

Vlado Damjanovski

CCTV

Networking and Digital Technology

SECOND EDITION

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Second Edition

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Preface

Closed Circuit Television, commonly known as **CCTV**, is an interesting area of television technology. It is usually used in surveillance systems, but a lot of components and concepts can be implemented in an industrial production monitoring system, or, equally, in a hospital or university environment. So, even though the majority of readers would be looking at this book as a great help in understanding and designing surveillance systems, my intention was not to limit the topics to this area only.

This book you are holding in your hands is a new and enhanced version of the previous edition of **CCTV**, which was published in 1999. During the past five years, so much has happened in the closed circuit television industry that there was a need for a new and updated edition. I was pleased to see the previous book being so highly valued by many readers, as well as constantly rated with five stars on many web sites, including the popular Amazon.com. This has made me even more committed to making this new edition even better and more informative. I certainly could not change the contents of the previous edition since the basics of CCTV are still the same, but I did "fine tune" certain sections, added some new illustrations, but most importantly I enhanced the contents with new chapters on Digital and Networking in CCTV.

I have tried to cover the theory and practice of all components and fundamentals of CCTV. This is a very wide area and involves various disciplines and technologies from electronics, telecommunications, optics, fiber optics, digital image processing, programming, and, as of the last few years, networking, IP communications, and digital image processing. So, my intention was to have a new book which still encompasses the basic concepts of CCTV but also includes, explains, and demystifies digital CCTV, video compressions, and networking.

Analog television is a complex technology, especially for people who have never had the opportunity to study it, but understanding digital is even harder without understanding analog CCTV. So, if you are not familiar with the analog CCTV, do not think even for a moment that you can bypass it and go straight to digital and networking. Everything makes so much more sense in the digital once you know the analog CCTV.

As with the previous edition I had to read and learn new things myself, and then I tried to put everything into the same style and perspective as the previous chapters. Understandably, I did not want to reinvent the wheel, but I made efforts to simplify and explain the most important aspects of these new technologies. I would not have felt comfortable writing about these new subjects if I did not have some practical experience (though modest, at least so far), so that I tried to see it from a CCTV practical perspective. Should you be interested in more in-depth knowledge of networking and digital there are numerous books I would recommend (some are listed in the Bibliography section), but this book will give you a good summary and basics about the relevant CCTV aspects.

As with the previous edition, I have deliberately simplified explanations of concepts and principles, made many illustrations, tables, and graphs for better understanding, and tried to explain them in a

reasonably plain language. Still, a technical-minded approach is required.

Keeping up to date with the latest technologies and products was made easier through my involvement as editor of the international magazine for Closed Circuit Television, **CCTV focus** (***www.cctv-focus.com***). You can find many new technological topics and most up-to-date articles on the magazine's web site. The **CCTV focus** magazine was launched in 1999, the same year the previous edition of this book was published, and it quickly became one of the most respected magazines in the CCTV industry. It has already been translated into Russian and most likely will be translated into Chinese and German as well. You will find it the best extension of this book, for it is continuously updated with the latest topics, most of which are downloadable in Acrobat PDF format.

Another associated web site that could be extremely useful is the **CCTV Labs** web site (***www.cctvlabs.com***). CCTV Labs is my own company, specializing in consultancy, design, training, and publishing. The CCTV Labs web site was started in 1995 with the very first edition of the book **CCTV** and is now one of the longest serving CCTV web sites on the Internet. My intention was to have as much useful information on this web site as possible, and I am proud to say that the CCTV Labs web site is now one of the most frequently visited web sites in the world (in the CCTV industry).

The CCTV Central section of the CCTV Labs web site lists all the known businesses in the world. By visiting the CCTV Labs web site, you have instant access to almost every CCTV product, company, and manufacturer. Soon we will have it categorized and will include search tools for finding products and technologies.

This book is intended for, and will be very helpful to, installers, salespeople, security managers, consultants, manufacturers, and everyone else interested in CCTV, providing they have some basic technical knowledge.

The specially designed CCTV test chart printed on the back cover of the book will help you in video-quality testing, as explained in the last chapter of the book. This will be very handy for evaluating cameras, monitors, and transmission, but also the playback quality of recording systems, regardless of the compression they use. For readers who need a bigger and better test chart, CCTV Labs produces a high-resolution, light-framed A3 format of the same chart, which can be ordered from the CCTV Labs web site. The CCTV Labs test chart has been widely accepted, to the point that over 500 manufacturers and businesses worldwide are now using it. It is a great tool to check the quality of your system and compare it with others.

In addition to the test chart, CCTV Labs has also produced a specialized programmable test pattern generator (CCTV Labs TPG-8), the only such tool in the industry. It offers solid reference signals for testing a variety of system parameters. This is not part of the book, although it has been designed as a logical extension of the CCTV Labs test chart, so we decided to offer a special discount of 10% to all readers who decide to order it and mention this book as a reference.

So much has changed in the five years since the last edition of this book was published by Butterworth-Heinemann (now Elsevier) that the question became not whether a new edition should be written but only when.

I would like to thank many readers who have already made numerous suggestions and corrections. Readers who themselves write technical articles would know that no matter how many times one goes through one's own text will still find things that could be corrected, or be said somehow differently, and unavoidably there will be some errors, although I did my best to elminate them. So please, feel free to write to me if you find something needs to be changed or corrected for future editions. I am especially thankful to Nicolas Echave from Argentina, for his observations and suggestion in the section for calculating the light falling onto an imaging chip, as well as Bernard Cuzzillo from Berkeley, California, for his suggestions regarding correct light measurements using a photo camera.

I would also like to thank my colleague Les Simmonds for his assistance in providing me with some nice oscilloscope measurements and screen shots.

I owe special thanks to Elsevier and its staff for making this book a reality, and in particular, I would like to thank Pam Chester, Jennifer Soucy, and Sarah Hajduk.

This book has been made possible by Elsevier, as well as the CCTV manufacturers who have believed in me and co-sponsored this edition. These are: Ademco Video Systems, Axis Communications, Bosch Security Systems, Dallmeier Electronic, Elbex, Fast Video Security, Geutebrück, ITV, and Pelco.

The biggest thanks should go to **CCTV Labs** and **CCTV focus** magazine for their "loss of productivity" during my engagement with this book.

Thank you for purchasing the book and I hope you enjoy reading it.

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Sydney, November 2004

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CCTV

Introduction

This book has 14 chapters and they are written in a logical order.

Chapter 1, **SI units of measurement,** introduces the basics of the units of measurement which I thought are important to mention, even though they are not only a CCTV subject, but rather a technical issue. Many products, terms, and concepts exist in the world of CCTV which sooner or later need to be referred to with a correct unit. SI units are suggested by the ISO (the International Standardization Organization), and if we accept these units as universal it will make our understanding of the products and their specifications clearer and more accurate. I have also listed the common metric prefixes because I have found a lot of technicians do not know them. If you are an engineer or have a good technical background, you may not find this chapter of interest, so you can go directly to Chapter 2.

Chapter 2, **Light and television,** starts with a little bit of history so we can gain a wider perspective of the television revolution. Then we go to the very basics of human vision: light and the human eye. It is necessary to explain the human eye and how it works because television relies greatly on the human eye's physiology. It is interesting to compare the similarities between the eye's and the camera's operation.

Optics in CCTV is Chapter 3, which focuses on the first and important product used in CCTV, the lens. Apart from the discussion on how lenses work and what their most important features are, there is also a practical explanation of how and what to adjust (ALC and Level) on a lens, how to determine a focal length for a particular angle of view, and very important for CCTV, how back-focusing should be done. Also, C and CS-mounts are discussed and explained, as well as various chip sizes.

Chapter 4, **General Characteristics of television systems,** is very important, especially for readers without prior knowledge of how television works. I have discussed both major standards PAL and NTSC. I do apologize to readers using the SECAM for not going into detail on this standard. I simply could not find sufficient literature to study it, although there are many similarities with PAL, at least in the number of lines and fields per second used. General discussion on resolution is also included, and more importantly the difference between a broadcast signal and CCTV video signal. Near the end of the chapter I have also mentioned the most common instruments used in TV and what they measure. At the end, I have included tables that show the differences between various television system subgroups, as well as a listing of all the countries in the world with their adopted TV system.

Chapter 5, **CCTV cameras**, is probably the most interesting chapter in the book. It discusses at length the concepts of CCD cameras, various designs, and camera specifications. Here, I have also included a discussion of measurement and calculation of light coming onto a camera, power supplies, and voltage drops. I consider these very important practical issues which I have been asked about very often. Although they seem trivial, a lot of problems have been caused by improper camera setting or powering (unregulated or overrated power supply, thin wires, high-voltage drop). I found it suitable to discuss this issue in the camera section because power supplies form a part of the camera assembly. I have also included, at the end of this chapter, a very practical checklist which you or your installers can use in order to make the CCTV installation trouble free.

CCTV monitors are discussed in Chapter 6, and I have devoted space to both B/W and color monitors. Obviously, my main concentration is on the CRT monitors, as they are the most common in CCTV today. You will find explanations on various important issues associated with monitors, like gamma, the impedance switch, and viewing conditions. At the end of this chapter, I have included a description of some major new developments in the display technology. At the time of the release of the previous edition of this book, many of these technologies were only technical news, but today some of them have been or are being widely adopted.

In Chapter 7, **Video processing equipment,** I have encompassed the "good old" sequential switchers and then the matrix switchers, as representatives of the "analog" processing range, and of course quads, multiplexers, video motion detectors, and frame stores as representatives of the "early digital" range.

Chapter 8, **Analog video recorders,** discusses their very important role in CCTV. Although slowly being forgotten, the VHS format is explained as it is still a common type, but I have also included the S-VHS format. Digital video storage, however, is becoming increasingly popular, and I found it important to say a few words about it in a new chapter.

Chapter 9, **Digital video**, is the main reason for this new book. From the time of the previous edition of this book (1999) when digital was only hinted, now (2005) there is almost no system installed without a digital video recorder or network in place. This heading discusses all the intricacies of digital, and why it is important to compress. Also, it analyzes the various compressions and puts them in a logical order.

Transmission media, Chapter 10, is one of the biggest owing to the large variety of transmission types used in CCTV. Clearly, the coaxial cable is the most common and widely accepted, so I have dedicated most of the space to the coaxial cable concept. Through my practical experience, and I believe a lot of readers will agree, I have found that the majority of problems in the existing or just recently installed CCTV systems are due to bad cable installations and/or terminations. So I have devoted some space on the actual termination techniques. In the rest of the chapter you will find explanations on the other media, like twisted pair, microwave, RF wireless, infrared, telephone lines, and, the most important for the near future (at least in my opinion), fiber optics. You will find quite a lot of space devoted to fiber optics, starting with the explanation of the concepts, light sources used in fiber, cables, and installation techniques. This technology is not as new as some may think; rather, it has become very affordable and easier to use and thus more common in larger CCTV systems.

Chapter 11, **Networking in CCTV**, includes the other important new technology we now face: Networking and IT technology. This goes hand in hand with the digital CCTV, but logically comes after the Transmission Media chapter as it does belong to the transmission section. The Networking in CCTV chapter does not intend to substitute the more in-depth literature you can find on networking and IT technology (since there is plenty of it around) but it gives the "non-IT" reader some basic concepts and understanding of the increasingly more important Information Technology.

Chapter 12, **Auxiliary equipment in CCTV,** includes the good old discussion on pan and tilt heads, housings, lighting, infrared lights, ground loop correctors, lightning protection, video amplifiers, and distribution amplifiers.

The previous twelve chapters focus on the equipment side of a CCTV system, so in Chapter 13, **CCTV System design**, I discuss my understanding of how to design a CCTV system. This chapter is based purely on practical experience and on feedback from installers and users. You do not have to accept this as the only way to design a system, but I have certainly found it is very efficient and accurate. In this chapter I have also included the actions taken after the system design is finished and installed. These are: commissioning, training, and handing over. Preventative maintenance is often forgotten, but it is an important part of a complete CCTV system offer. Even if preventative maintenance is done after the system is finished I think it is important for this to be listed here as part of the complete picture of CCTV.

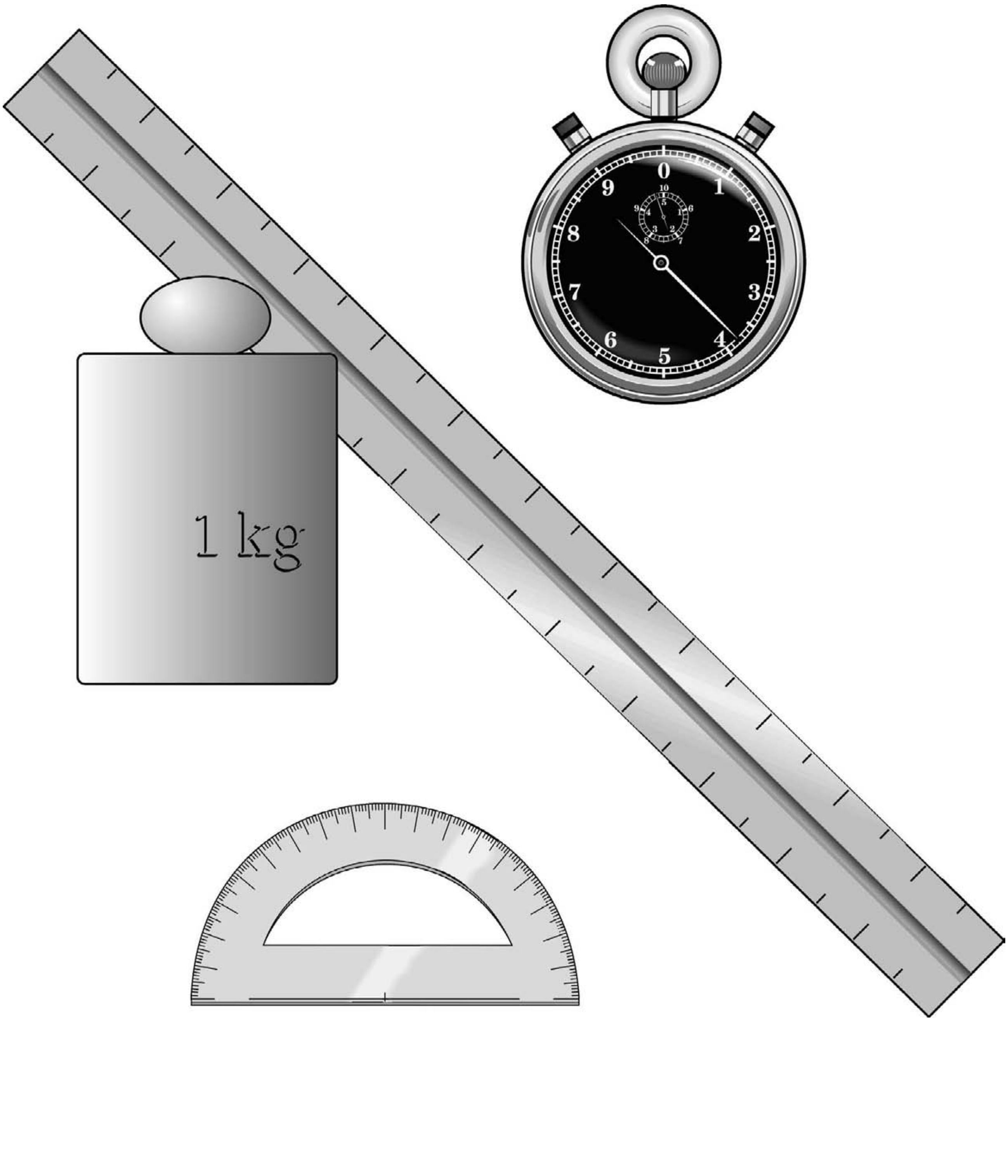
The last, Chapter 14, **Video testing**, advises readers on the usage of the CCTV Labs test chart, which I traditionally put at the back cover of the book in order to help you measure and test video. Many people found the CCTV Test Chart very useful, and, not surprisingly, it has become a de facto industry standard, so it might be interesting to know how to use it. We regularly update and enhance the chart adding some more useful features. Now you can use the test chart not only to determine camera resolution, but also to see if you can recognize a person at a certain distance. For the more dedicated CCTV technicians, the same test chart is also available on A3 format, foam framed, and printed on a nonreflective chemical proof paper with durable and stable colors. Also, the full description on how to use the Test Chart, apart from appearing in the book, is also available on our web site. Finally, there is the new CCTV Labs test pattern generator, the first programmable test pattern generator in the industry, designed and manufactured according to our specifications. Unfortunately, we cannot include this product with the book, but hopefully, by reading how useful it can be in your video tests, you may be able to order via the CCTV labs web site (***www.cctvlabs.com***).

Appendix A, **Common terms used in CCTV,** explains exactly what the heading says. I have tried to include all the terms, acronyms, and names one might come across in CCTV and accompanying fields.

In Appendix B, **Bibliography and acknowledgments**, you can find some interesting reference material and web sites, some of which I have used in the preparation of this book.

In Appendix C, **All the CCTV Links in the World**, we include a complete listing of all known CCTV businesses in the world, courtesy of **CCTV Labs** and **CCTV focus** magazine.

I hope that this book will be very helpful and informative in all your CCTV work.


1 kg

1. SI units of measurement

The basic units

The Laws of Physics are expressions of fundamental relationships between certain physical quantities.

There are many different quantities in physics. In order to simplify measurement and to comply with the theory of physics, some of them are taken as basic quantities, while all others are derived from those basic ones.

Measurements are made by comparing the magnitude of a quantity with that of a given unit of that quantity.

In physics, which Electronics and Television are a part of, the ***International system of units*,** known as **SI** (from the French *Système Internationale*), is used.

The following are **the seven basic units**:

Unit	**Symbol**	**Measures**
Meter	[m]	length
Kilogram	[kg]	mass
Second	[s]	time
Ampere	[A]	electric current
Kelvin	[K]	temperature
Candela	[cd]	luminous intensity
Mole	[mol]	amount of substance

These basic units are defined by internationally recognized standards.

The standard for meter, for example, until 1983 was defined as a certain number of wavelengths of a specific radiation in the spectrum of krypton. In October 1983 it was redefined as the distance that light travels in vacuum during a time of 1/299,792,458 second.

The standard of kilogram, for example, is the mass of a particular piece of platinum-iridium alloy cylinder kept at the International Bureau of Weights and Measurements in Sèvres, France.

The basic unit of time, the second, was defined in 1967, as a "time required for a Cesium-133 atom to undergo 9,192,631,770 vibrations."

Kelvin degrees have the same scale division as Celsius degrees, only that the starting point of 0° K is equivalent to –273° C and this is called the ***absolute zero***.

All other units in physics are defined with some combination of the above-mentioned basic units. For example, an area of a block of land is defined by the equation:

$$P = a \times b$$

where a is the width of the block of land, and b is the length. If both a and b are expressed in meters [m], the product P will be expressed in [m^2]. We should mention that in mathematics the multiplication is not always represented with the × sign as above, but very often a dot · is used in between the factors being multiplied, or sometimes even without a symbol at all.

We all know that speed, for example, is defined as [m/s], although we quite often use [km/h]. We can easily convert [km/h] into [m/s] by knowing how many meters there are in a kilometer and how many seconds there are in an hour.

SI units are almost universally accepted in science and industry throughout the world, and we should all be aware that measurements like "inches" for length, "miles per hour" for speed and "pounds or stones" for weight should be used as little as possible. They often cause confusion in people from various professions and various parts of the world. If you use SI units, more people will understand you and your product. Also, it is easier to compare products from various parts of the world if they use the same units.

Another very important thing to clarify is that every symbol in the SI system has a precise meaning relative to the letter used (capital or small). So, a kilometer is written as [km], not [Km] or [klm]. A megabyte is written as [MB], not [mB]. A nanometer is written as [nm], not [Nm] and so on. As technical people involved in closed circuit television, we should stick to these principles.

Derived units

All other physical processes can be explained and measured using the basic units. We will not go into the details of how they are obtained, nor is it the purpose of this book to do so, but it is important to understand that there is always a fundamental relation between the basic and derived unit.

The following are some of the derived SI units, some of which will be used in this book:

Quantity	Unit	Symbol / Definition
Area	Square meter	m^2
Volume	Cubic meter	m^3
Velocity	Meters per second	m/s
Acceleration	Meters per second per second	m/s^2
Frequency	Hertz	Hz = 1/s
Density	Kilograms per cubic meter	kg/m^3
Force	Newton	$N = kg \cdot m/s^2$
Pressure	Pascal	$Pa = kg/m \cdot s^2$
Torque	Newton meter	$T = N \cdot m$
Energy, work	Joule	$J = N \cdot m$
Power	Watt	W = J/s
Electric charge	Coulomb	$C = A \cdot s$
Electric potential	Volt	$V = \Omega/A$
Electrical resistance	Ohm	$\Omega = V/A$
Electrical capacitance	Farad	F = C/V
Conductance	Siemens	S = A/V
Magnetic flux	Weber	$Wb = V \cdot s$
Magnetic field intensity	Tesla	$T = Wb/m^2$
Inductance	Henry	H = Wb/A
Illumination	Lux	$lx = lm/m^2$
Luminous flux	Lumen	$lm = cd \cdot steradian$
Luminance	Nit	$nt = cd/m^2$

Metric prefixes

When the number of units (i.e., the value) for a particular measurement is very high or very small, there is a convention for using certain symbols before the basic unit and each has a specific meaning. The following are metric prefixes accepted by the international scientific and industrial community that you may find not only in CCTV but also in other technical area:

Prefix	Multiple	Symbol
exa-	10^{18}	E
peta-	10^{15}	P
tera-	10^{12}	T
giga-	10^{9}	G
mega-	10^{6}	M
kilo-	10^{3}	k
hecto-	10^{2}	h
deca-	10	D
unity	$10^{0} = 1$	
deci-	10^{-1}	d
centi-	10^{-2}	c
milli-	10^{-3}	m
micro-	10^{-6}	μ
nano-	10^{-9}	n
pico-	10^{-12}	p
femto-	10^{-15}	f
atto-	10^{-18}	a

By using these prefixes, we can say 2 km, referring to 2000 meters. If we say 1.44 MB, we are thinking of 1,440,000 bytes. A very common measurement of data transmission speed over networks is expressed in megabits per second (Mb/s), which is different from megabytes per second (MB/s). One byte is equal to 8 bits, and they are denoted with lower case “b” for bits and capital “B” for bytes. A nanometer will be

0.000000001 meters. The frequency of 12 GHz would be $12 \cdot 10^9$ = 12,000,000,000 Hz and so on.

A very common unit used these days in CCTV when handling hard disk drives is gigabytes (GB). One gigabyte is equal to thousand of megabytes, or a million of kilobytes. The correct value for binary 1 GB megabytes is 1024 MB (which is 2^{10}), and the correct binary value for 1 MB is 1024 kB. When hard disk manufacturers write 300 GB on their disks, this represents a decadic 300,000,000,000 bytes. So when such a hard disk is installed in the computer, the operating system reports 279 GB. This is the real binary value, and it is obtained by dividing 300,000,000,000 with 1024 to get kB, then with 1024 again to get MB, and finally with 1024 again to get GB.

Now that we have established the basics of a technically correct discussion that is, introduced the basic units of measurement, we can start with the fundamentals of all visions, including photography, cinematography, and television – ***light***.



2. Light and television

Let there be light.

A little bit of history

Light is one of the basic and greatest natural phenomena, vital not only for life on this planet, but also very important for the technical advancement and ingenuity of the human mind in the visual communication areas: photography, cinematography, television, and multimedia.

Even though it is so "basic" and we *see* it all the time and it is all around us, it is the single biggest stumbling block of science. Physics, from a very simple and straightforward science at the end of the nineteenth century, became very complex and mystical. It forced the scientists in the beginning of the twentieth century to introduce the postulates of quantum physics, the "principles of uncertainty of the atoms," and much more – all in order to get a theoretical apparatus that would satisfy a lot of practical experiments but, equally, make sense to the human mind.

This book is not written with the intent of going deeper into each of these theories, but rather I will discuss the aspects that affect the television and video signals.

The major "problem" scientists face when researching light is that it performs a dual function: it behaves as though it is of a wave nature (nonmaterial) – through the effects of refraction and reflection – but it also appears as though it has material nature – through the well-known photo-effect discovered by Heinrich Hertz in the nineteenth century and explained by Albert Einstein in 1905. As a result, the latest trends in physics are to accept light as a phenomenon of a "dual" nature.

It would be fair at this stage, however, to give credit to at least a few major scientists in the development of physics, and light theorists in particular, without whose work it would have been impossible to attain today's level of technology.

Isaac Newton was one of the first physicists to explain many natural phenomena including light. In the seventeenth century he explained that light has a particle nature. This was until Christian Huygens, later in that century, proposed an explanation of light behavior through the wave theory. Many scientists had deep respect for Newton and did not change their views until the very beginning of the nineteenth century when Thomas Young demonstrated the interference behavior of light. August Fresnel also performed some very convincing experiments that clearly showed that light has a wave nature.

A very important milestone was the appearance of James Clerk Maxwell on the scientific scene, who in 1873 asserted that light was a form of high-frequency electromagnetic wave. His theory predicted the speed of light as we know it today: 300,000 km/s. With the experiments of Heinrich Hertz, Maxwell's theory was confirmed. Hertz, however, discovered an effect that is known as the ***photo-effect***, where light can eject electrons from a metal whose surface is exposed to light. However, it was difficult to explain the fact that the energy with which the electrons were ejected was independent of the light

intensity, which was in turn contradictory to the wave theory. With the wave theory, the explanation would be that more light should add more energy to the ejected electrons.

This stumbling block was satisfactorily explained by Einstein who used the concept of Max Planck's theory of quantum energy of photons, which represent minimum packets of energy carried by the light itself. With this theory, light was given its dual nature, that is, some of the features of waves combined with some of the features of particles.

This theory so far is the best explanation for the majority of light behavior, and that is why in CCTV we apply this "dual approach" theory to light.

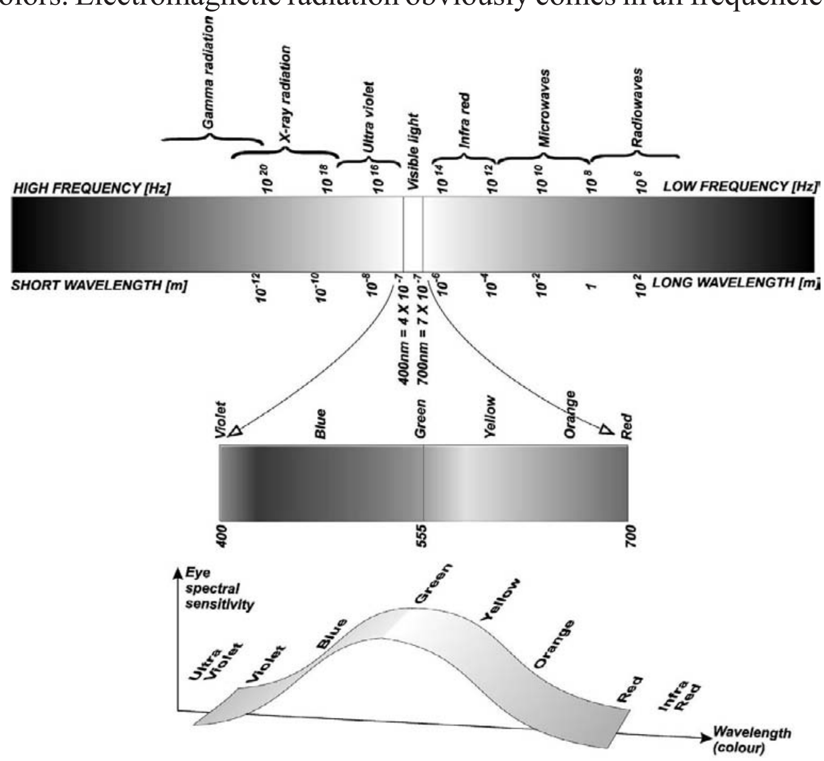
In explaining the concepts of lenses used in CCTV, we will be using, most of the time, the wave theory of light, but we should always have in mind that there are principles like the CCD chip's operation, for example, based on the light's particle behavior. That is why, in this case, we will be using the material approach to light.

Clearly, in practice, light is a mixture of both approaches, and we should always have in mind that they do not exclude each other.

Light basics and the human eye

Light is an electromagnetic radiation. The human eye is sensitive to this radiation and to various radiation frequencies it picks up as colors. Electromagnetic radiation obviously comes in all frequencies, i.e., wavelengths, as can be seen in the drawing on the right. The visible light occupies only a very little "window" in this range. This window is between 380 nm and 780 nm. We take this, however, to be roughly from 400 nm to 700 nm, for easy remembering.

The 400 nm corresponds to violet and 700 nm to red color. There is a continuous color change from the violet to blue, green, yellow, orange, and red as the wavelength increases. Many experiments and tests have been done to check the sensitivity of an average human eye and, as can be seen from the drawing, **not all colors produce the same effect on the eye's retina**.



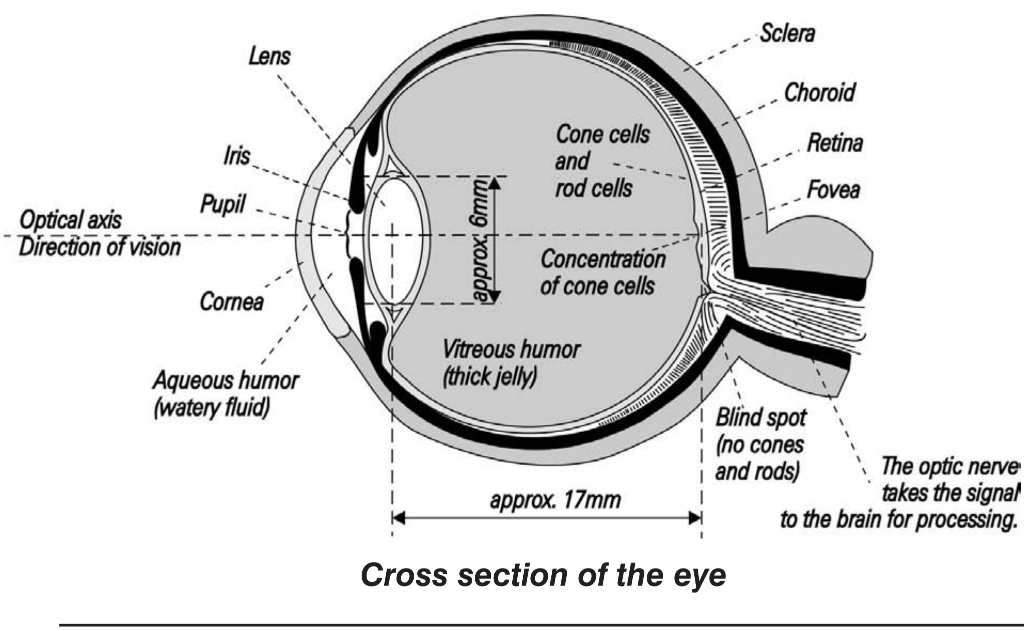
The electromagnetic spectrum and human's eye sensitivity

Green color excites the eye the most. In other words, if we have all the wavelengths of the light with an equal amount of energy, the green will produce the highest "output" on the retina. Frequencies higher than the violet (wavelengths shorter than 400 nm) and lower than the red (wavelengths longer than 700 nm) cannot be detected by the "average" human eye. I emphasize this "average" because human eye sensitivity is a statistical curve. There are people who are "color blind," which means their eye spectral sensitivity is different (usually narrower) from the one shown. Some "color-blind" people cannot see red color, some cannot see blue. A trained, professional eye of a painter or a photographer may develop very high sensitivity for detecting various frequencies (colors) which might look the same to others. Some may even extend their minimum and maximum detectable frequency limit, that is, see deeper violet or red colors that are invisible to other individuals.

A very interesting question to ask ourselves is why is the eye's spectral sensitivity maximum in the green color area (at around 555 nm)? This can be associated with the fact that of all the sun's energy that penetrates the Earth's atmosphere, the biggest amount is contained in the wavelengths at around 555 nm.

After millions of years of evolution of life on this planet, we (and most of the animals) have developed vision using wavelengths that are most readily available (at least during the daytime). An obvious alternative is the night vision eye characteristics of animals whose food targets are warm-blooded mammals. Body heat is nothing more than infrared radiation. Typical examples are snakes, cats, and owls. Some snakes, for example, apart from using the eyes for general vision, also have infrared sensitive pit organs with which they can detect temperature change of less than 0.5º C (1º F). Cats, including wild cats such as leopards, pumas, and other members of the cat family, are known for their good nighttime vision, which would mean that their near infrared response is far better than that of the human eye.

We will concentrate on the human eye, and it is very important to understand the "construction" of it. This will perhaps be of general interest, but we will also see a lot of conceptual similarities between the eye and the TV camera construction.



Cross section of the eye

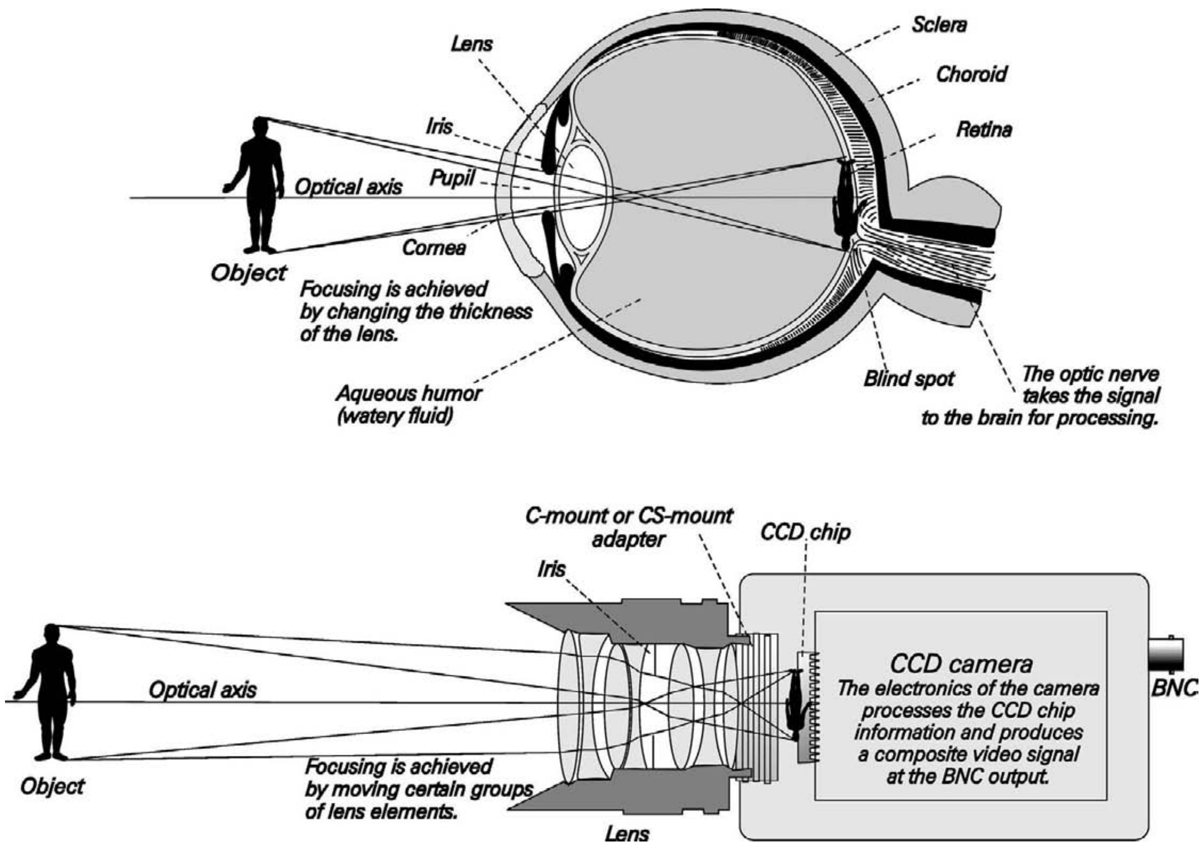
This cross section shows that the eye has a lens that focuses the image onto the retina. The retina is actually the "photosensitive area," which is composed of millions of cells, called **cones** and **rods**. These cells can be considered a part of our nervous system. The **cones are sensitive to the medium and bright intensity of light and they actually sense the colors**. The **rod**

cells are sensitive to lower light levels, and they do not distinguish colors. We use rod cells to see at night, which means **when it is dark we cannot distinguish colors**.

The number of cones in each eye is approximately 10 million, and the number of rods is over 100 million. The cones are concentrated around the area where the optical axis passes. This area is colored with a yellowish pigment and is called the **fovea**. The fovea is the central area that our brain processes and although it is a small area, the concentration of cones there is approximately 50,000. The average focal length of an eye (i.e., the distance between the lens and the retina when an infinitely distant object is being viewed) is approximately 17 mm. This focal length gives an undistorted image in a solid angle of approximately 30°. This is also the size of the area most populated with the cone cells. **This is why an angle of about 30° is considered a standard angle of vision.**

The concentration of cones increases toward the center of the optical axis with the peak being at only 10°. Each of these cone cells is connected to the brain via **separate optic nerves, through which electrical pulses are sent to the brain.** The eye, of course, sees a much wider angle, since the retina covers nearly a 90° solid angle and there are cones outside the yellow area as well, but these other cones are connected to each nerve in groups. With this area we do not see as clearly as when we use the single nerve cones, and that is why this area is known as the **peripheral vision area**.

The brain's "image processing section" concentrates on 30°, although we see best at around 10°. This processing is further supported with the constant eye movement in all directions, which is equivalent to a



Eye – Camera similarities

pan/tilt head assembly in CCTV.

For a single lens reflex (SLR) camera the standard angle of view of 30° is achieved with a 50 mm lens, for a 2/3" camera this is a 16 mm lens, for a 1/2" camera a 12 mm lens, and for a 1/3" camera an 8 mm lens. In other words, images of any type of camera, taken with their corresponding standard lenses, will be of a very similar size and perspective as when seen through our eyes.

Lenses shorter in focal length give a wider angle of view and are called ***wide-angle*** lenses. Lenses with longer focal length narrow the view, and therefore they look as if they are bringing distant objects closer, hence the name ***telephoto*** ("tele" meaning distant). Another matter of interest associated with CCTV is that by knowing the focal length of the eye and the maximum iris opening of approximately 6 mm, we can find the equivalent "F-number" (discussed later in the book) of the eye:

$$F_{\text{number-eye}} = 17/6 = 2.8$$

With such a fully opened iris we can still see quite well in full moonlight (this is approximately 0.1 lux at the object). Have this number in mind when comparing the minimum illumination characteristics of different cameras.

The **focusing that the human eye** does in order to see objects at various distances **is achieved by changing the thickness of the lens**. This is done by the ciliary muscles. If the eye is normal, it should be able to focus from infinity down to a minimum distance of about 20 cm in early childhood, to 25 cm at age 20, to 50 cm at age 40, and to 5 m at age 60. When we look at something very far away, that is, eye focused on infinity, the ciliary muscles are relaxed and the lens is **thin**.

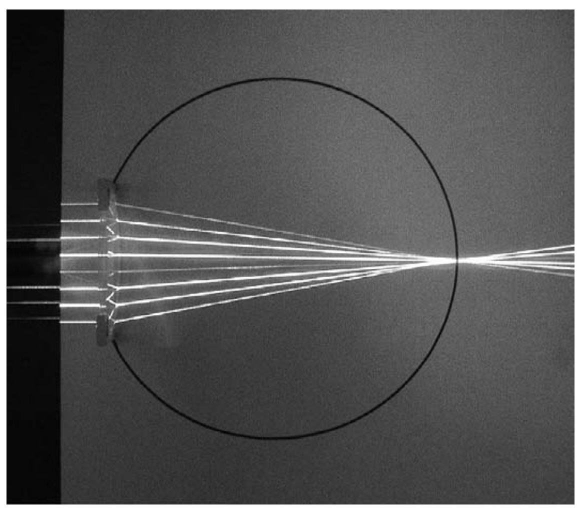
If the eye cannot focus at infinity that vision defect is called ***nearsightedness*, or *myopia***. Such eyes require glasses to help the "defective" human eye lens focus the image on the retina. These glasses are sometimes called reducing glasses because they have a negative focus (or diopter).

A diopter is the inverse value of the focus of a lens, where the focus is expressed in meters. Reducing glasses have a negative diopter. So, "reducing" glasses with a diopter of – 0.5, for example, have a negative focus of 1/(– 0.5) = – 2 m.

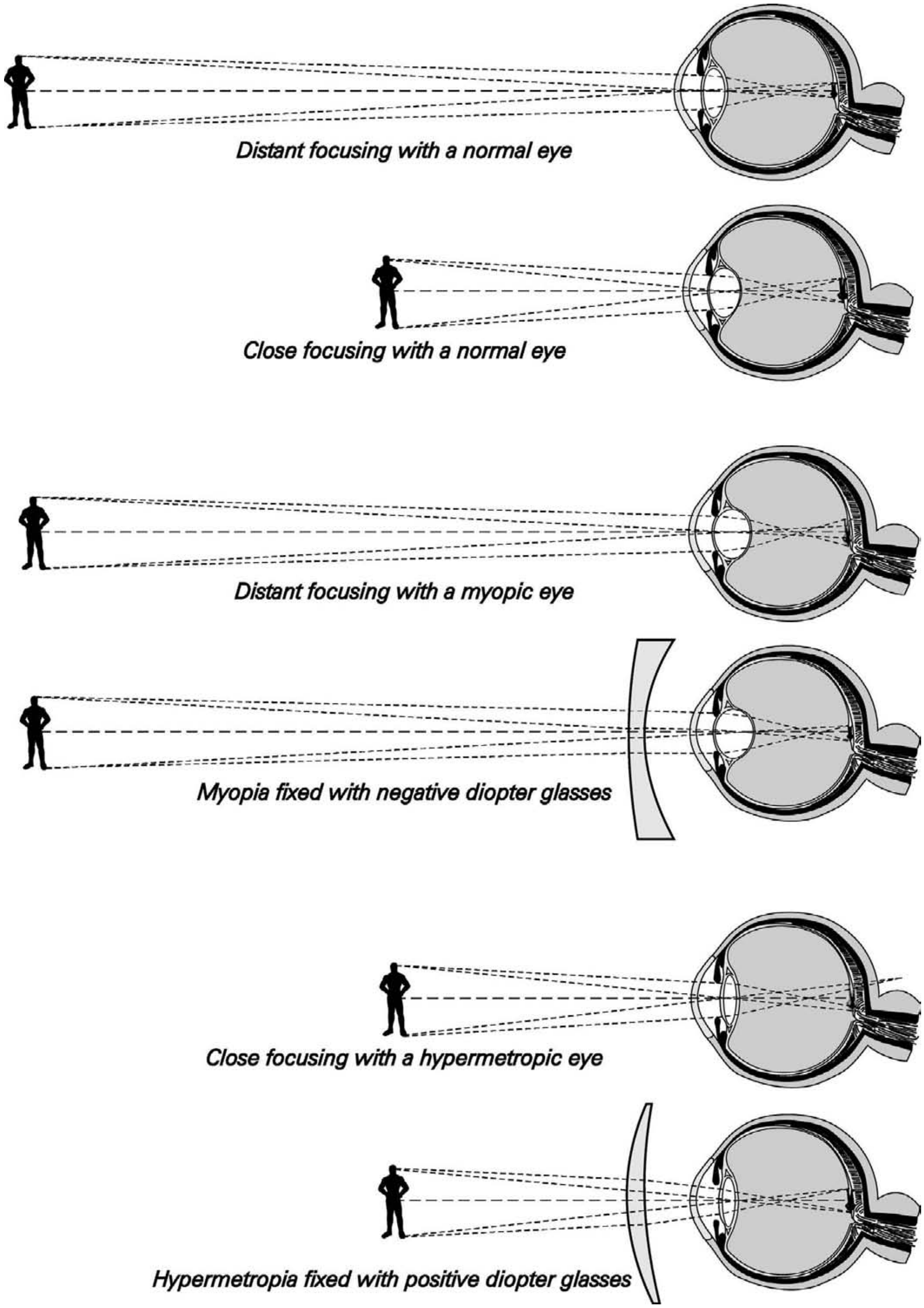
Another defect an eye may have is when it cannot focus on an image that is very close, that is, the eye's lens cannot be thickened enough for some reason.

This defect is called ***farsightedness*, or *hypermetropia***.

People with hypermetropia need glasses to be able to see close objects sharply. These glasses would need to have the opposite characteristics from those in the previous case, that is, they would have to be magnifying glasses with positive focus and diopter.



Simulation of how the eye works



Correcting eye deficiencies with glasses

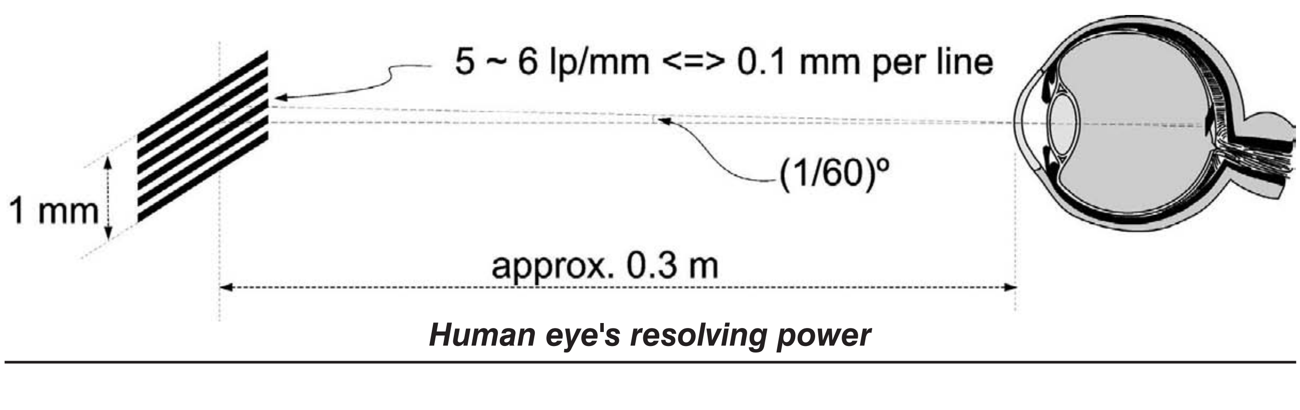
Two eyes produce images that when mixed in our brain, give a stereoscopic impression of the volume of space. If we cover one eye, it is very hard to judge the “three-dimensionality” of the space in front of us. The distance between the eyes (60–70 mm) ensures our perception of three dimensions up to 10–15 m away. After this distance it is very hard to judge which of two objects is closer. This can be experimented with by trying to see two objects in the air at different long distances, for example. If we are looking at, let us say, two distant trees, the brain brings a conclusion on the basis of the soil and perspective in front of us, but the perspective “decision” would not be concluded on the basis of the eye’s “stereoscopic mechanism.”

It is amazing when you think about the complexity of the eye and the brain’s power for “image processing.” We perform these operations hundreds of times a day without even thinking about it, not to mention the fact that the images that fall on the retina are upside down, owing to the nature of the optical refraction, and we also do not consider the eye movement in all directions when we follow something. All of these things are being deciphered and controlled by the brain.

The “eye–brain” configuration is far superior to any camera that the human mind has, or will ever invent. But, as technical people, we can say that by understanding how the eye “works” and using the ever improving visual technology, both in hardware and software, we are getting better images and more sophisticated information about the world around us and we can view things the human eye cannot see or monitor things in places where the human cannot be present.

With experiments and testing it has been found that **the most a human eye can resolve is no more than 5 ~ 6 lp/mm** (line pairs per millimeter). This refers to an optimum distance between eye and object of around 0.3 m, as when we are reading a fine text. This equates to a minimum viewing angle of about one-sixtieth of a degree (1/60°). So, **1/60º is considered the limit of angular discrimination for normal vision**. We can use this minimum angular vision for better understanding and optimizing the psychophysiology of the viewing.

A known viewing distance parameter, from the Monitors chapter later in the book (Chapter 6), recommends for CCTV viewing a distance of around seven times the monitor height. So, we should understand that the viewing distance is an important factor for the experience of seeing fine details in an image. It is of no use if a viewer gets closer to the monitor, but it is also not going to get any better if he is positioned further away from the monitor screen.



Human eye's resolving power

Light units

Light is a physical phenomenon but is interpreted by psychological processes in our brain. It is, therefore, a bit more complex to measure than other physical processes. Some prerequisites have to be established in order to make objective measurements. One of these is the bandwidth of the light frequencies considered, and this is usually from 400 nm to 700 nm. All of the frequencies contribute to the light energy radiated by the source.

Let us, first of all, make clear the kind of light sources we have. The basic division is into two major groups:

- Primary sources (the sun, street lights, tungsten lights, monitor CRTs)
- Secondary sources (all objects that do not generate light but reflect it)

We do not apply the same type of measurement when measuring the amount of light radiated by a tungsten globe, for example, and the light reflected by an object. It is not the same if we are analyzing light radiated from a source in all directions, or just in a narrow solid angle. These are some of the reasons we have so many different units of light measurement.

The science that examines all these different aspects is called ***photometry***, and the units defined are called ***photometric units*.**

Many different units have been defined by various scientists, depending upon the point of view taken. Because of this, CCTV camera specifications are even harder to understand and describe precisely. But let us try to shed some light on these units and explain what they mean. We will start in a logical order, that is, the source of the light, traveling through space, falling onto an object, and finally as it is reflected from it.

Luminous intensity (***I***) is the illuminating power of a primary light source, radiated in all directions. The unit that measures this kind of light is the ***candela*** [cd]. **One candela is approximately the amount of light energy generated by an ordinary candle**. Since 1948 there has been a more precise definition of a candela as **the luminous intensity of a black body heated up to a temperature at which platinum converges from a liquid to a solid state**.

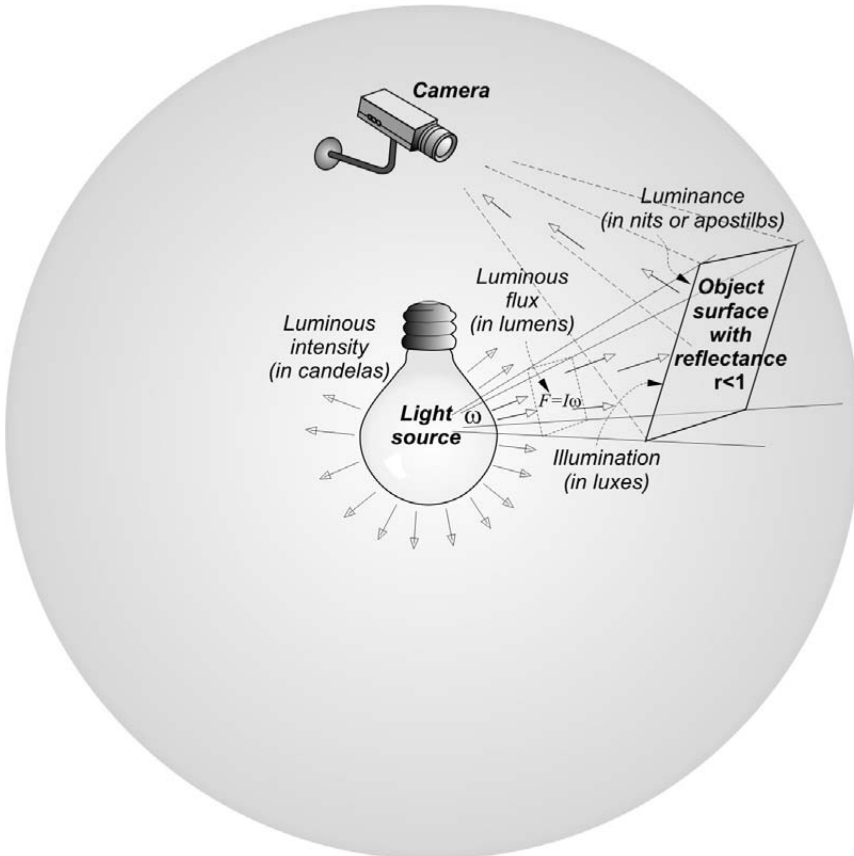
Luminous flux (***F***) is the luminous intensity but in a certain solid angle. The unit for luminous flux is, therefore, obtained by dividing the luminous intensity with 4 π (pi) radians (a sphere has 4 π = 12.56 steradian) and is measured in ***lumens*** [lm]. **One lumen is produced by a luminous intensity of 1 cd in one radian of a solid angle.**

Because the sensation of brightness depends on the human eye sensitivity, the luminous flux depends on the wavelength as well. For example, 1 watt of light power with 555 nm color (green) produces approximately 680 lm, whereas all other wavelengths, with the same light power, produce proportionally fewer lumens (see the eye spectral sensitivity curve). It is therefore meaningless to express light power in watts, even if, theoretically, light energy like any other energy can be expressed in watts.

Illumination **(*E*)** is the most commonly used term in CCTV, especially when referring to the camera's minimum illumination characteristics. Illumination is very similar to the luminance except that we are now referring to objects that are secondary sources of light.

Therefore, **the illumination of a surface is the amount of luminous flux on a unit area**.

When luminous flux of 1 lumen falls on an area of 1 m^2 (square meter), it is measured in **lumens per square meter** or **meter-candelas**, but it is better known as ***lux*** [lx].



Light units and their meaning

This means that if we have a sphere of 1 meter radius, a light source, with luminous intensity of 1 candela inside this sphere, it will produce illumination on the internal surface of 1 lx. Mathematically, this relation can be described as:

$$E = \text{Flux} / \text{Area} = F/A \qquad [\text{lx}] \qquad (1)$$

The flux F is, by definition, equal to luminous intensity times the solid angle, i.e.,

$$F = I \cdot \omega \qquad [\text{lm}] \qquad (2)$$

From the basics of volumetric trigonometry, and assuming a punctual source of light, we can express ω through the area *A* being lit and its distance from the source *d*:

$$\omega = A / d^2 \qquad [\text{rad}] \qquad (3)$$

When (2) and (3) are replaced in (1), we get

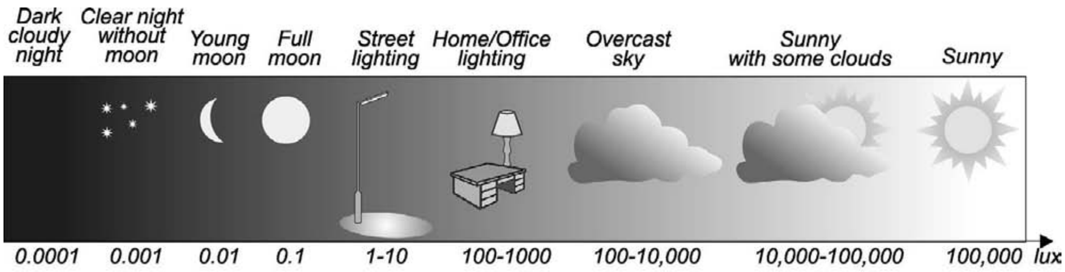
$$E = I / d^2 \qquad [\text{lx}] \qquad (4)$$

which means that **the illumination falls off with the square of the distance when the perpendicular area is being lit**. If, however, this area is at a certain angle to the incoming light, we can approximate

the real area with the projection at an angle θ, as per the diagram shown here. In that case the formula (4) becomes:

$$E = I \cdot \cos\theta / d^2 \qquad [\text{lx}] \qquad (5)$$

Typical levels of illumination are shown on the following drawing:



Some typical levels of illumination

Very rarely, in certain small areas and from very strong light sources, levels higher than 100,000 lx can be experienced (in the vicinity of a strong flashlight, for example). To describe such illuminations, higher units called ***phots*** are sometimes used. **One phot is equal to 10,000 lx.**

In American terminology, where square feet are still widely used instead of the SI units, illumination is expressed in **square-foot candelas**, or better known as ***foot-candelas***. Because of the "square meter – square foot" ratio, equal to nearly 10 (or more precisely 9.29), it is reasonably easy to convert luxes into foot-candelas and vice versa. Basically, if an illumination is given in foot-candelas, just divide it by 10 and the approximate value in luxes is obtained, and if a value is given in luxes, in order to convert it to foot-candelas, multiply it by 10.

Luminance (***L***) describes the brightness of the surface of either a primary or a secondary source of light. Since brightness embeds subjective connotation, luminance is used as an objective, scientific term. Luminance depends both on the luminous intensity of the surface itself and on the angle at which it is being observed. It is therefore measured per unit of projected surface area perpendicular to that direction. There are quite a few units for luminance. The internationally preferred metric unit is **nit. One nit is equal to one candela per square meter of projected surface area** (I/A). If, instead of candelas, lumens are used to describe the luminous flux of a source, the luminance will then be expressed in **apostilbs** [asb]. Things get a bit more complicated when we have a surface where the luminous flux radiated, or reflected, in a direction θ to the normal is directly proportional to cos θ. Such a surface will appear equally bright when seen from all directions because both the reflected light and projected surface area follow the same cosine law. This type of surface is called a **lambert** radiator or reflector (depending on whether the surface is a primary or secondary source of light) and is usually described as a **perfectly diffusing surface**. For the purpose of measuring such light luminance in the metric system, a unit called **lambert** was introduced. The equivalent American unit would be the **foot-lambert**.

How much of the illumination is seen by the camera depends not only on the intensity of the source itself, but also on the reflectivity of the object being illuminated. Obviously, it is not the same if the object is white as opposed to black. With the same amount of light we can, naturally, see more if the

objects are white. This is why we have to introduce another factor when talking about illumination, and this is the percentage of object ***reflectivity***. The definition of reflectivity could be described with the following simple relation:

$$\rho = \text{light reflected from surface / light incident on surface} = E/L \qquad [\%] \qquad (6)$$

Realistically, this percentage ranges from a very low 1% for black velvet to 32% for a typical soil surface and up to 93% for bright snow in the field of view. Caucasian human flesh has a reflectivity factor between 19% and 35%. The CCTV Labs test chart enclosed on the back cover of this book has an approximate reflectivity factor of 60~70%.

The reflectivity is an important factor when stating a camera's minimum illumination because with the same level of illumination and various reflectivity factors, an object may appear more or less bright, indirectly affecting the camera performance.

Measuring object illumination in CCTV

Very often you may have to measure and quantify the object illumination in your CCTV system. You can use lux meters available on the market for such measurement. When using such meters, you should check what is its measuring range. Typical lux meters have precision down to 1 lux (which might be sufficient for majority situations). Low light illuminations of below 1 lux (typical for night viewing) cannot be quantified unless you have a high-quality and expensive photographic light meter. There are a number of known brands on the market, such as Sekonic, Minolta, and Gossen. Some of them will even give you readings directly in luxes.

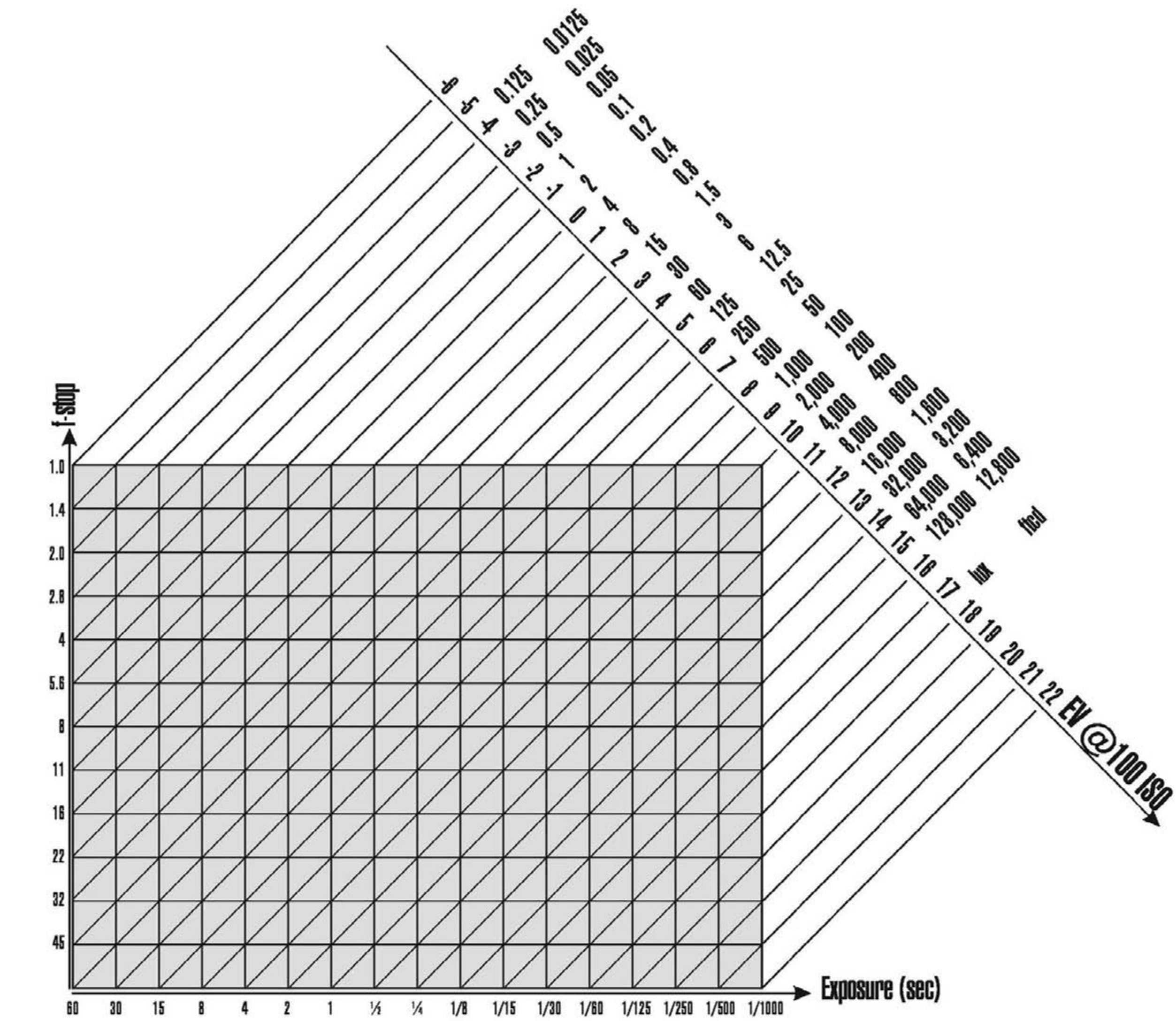
If you do not have a lux meter, a typical single lens reflex camera (SLR) lightmeter can be used to measure the same, although such measurements will not be shown in luxes, but rather as film exposure and F-stop setting. This could be an extremely useful tool, and here I will explain the principles and formula to calculate such lux measurement.



Photo courtesy of Pentax

A typical light measurement display in a modern SLR camera

Please note that most SLR cameras would have a light meter, while non-SLR cameras may not necessarily have it. So if you cannot find any indicators for exposure and aperture on your camera, you may not be able to make use of this. Please also note that a logical prerequisite for a more accurate measurement is to have the SLR camera



The EV graph to lux conversion using Exposure and F-stop measurements

have the same field of view as the potential (or existing) CCTV camera. For this reason the best lens to have on the SLR camera is a zoom lens so that you can adjust the angle of view as close to the CCTV camera as possible.

First, let us just refresh our memory about some basic rules of photographic film exposure.

The exposure indicators on all photographic cameras are in seconds, or to be more precise, in fractions of a second. This means that when a camera light indicator shows 125, it actually indicates 1/125 of a second. If the exposure is longer than 1 second, it is usually denoted with an “s” after the number; for example “2 s” indicates 2 seconds. Standard exposure numbers are 1; 2; 4; 8; 15; 30; 60; 125; 250; 500; and 1000. These are all parts of a second. There are cameras that can set the exposure for longer than 1 second and shorter than 1/1000. As you may notice, the values are chosen so that they represent approximately half of the previous number.

The indicators for the lens iris opening, or aperture, are shown as “F-stop” values. So the number “5.6”

indicates F-5.6. The higher this number is, the smaller the lens iris opening is. Typical F-stop numbers are 1.0; 1.4; 2; 2.8; 4; 5.6; 8; 11; 16; 22; 32; and 44. At each F-stop the opening is half the area size it was at the previous F-stop, that is, half the amount of light transmitted than the previous F-stop.

Reference No. (RN_t)	Speed (s)	Aperture (F-stop)	Reference No. (RN_f)
0	1	1	0
1	1/2	1.4	1
2	1/4	2	2
3	1/8	2.8	3
4	1/15	4	4
5	1/30	5.6	5
6	1/60	8	6
7	1/125	11	7
8	1/250	16	8
9	1/500	22	9
10	1/1000	32	10
11	1/2000	45	11
etc...			

The relationship between reference numbers, the exposure, and the F-stop

For a correct exposure of the film in your camera an internal light meter is used, which sets the correct time duration and aperture when exposing the film. In "Program" mode, both values are chosen automatically by the camera. In "Aperture-priority" mode, you set the F-stop and the camera computer selects the exposure. In "Exposure-priority" mode, it is the other way around; you select the exposure and the camera selects the aperture (i.e., F-stop).

Combinations of the exposure and F-stop can be such that they allow for equal amounts of light to get onto the film. For example, if you or the camera selects 1/30 s and F-5.6, you will produce the same effect on the film with 1/60 s and F-4. Of course, with the latter F-stop you would have a slightly narrower depth of field, but other than that the film will be correctly exposed too. Because of this "equality" of the amount of light with different exposure/F-stop combinations, photographic experts have advised an Exposure Value (EV) rating for the amount of light that can be measured by the camera light meters. We will not be going into detail of exactly how the light is measured inside the camera, as this would require a full book to cover all models, but in general there are "Averaging" light meters, "Spot" light meters, and "Multi-pattern" light meters. I will not discuss these in depth because they are beyond the scope of this book, but a majority of cameras would have at least the "Averaging" light metering. This is close enough for our CCTV applications where illumination levels can only be determined approximately.

When you buy your photo camera, you will usually find an EV graph somewhere inside the camera's manual, indicating its light measurement capability. This graph should look similar to the one shown in the picture on the previous page. Most of the time the EV graphs refer to a film (or CCD chip if it is a digital photo camera) sensitivity of 100 ISO, which is a pretty standard film. For this reason, in our calculations in this text, we have assumed a film setting on your camera of 100 ISO. Of course, any other film sensitivity can be used; you just need to adjust the findings accordingly.

The EV graph is very simple to read. For example, a combination of 1/30 s and F-5.6 makes an EV value of 10. The same exposure can be achieved with 1/60 s and F-4 since they also have a combined exposure value of 10.

The EV scale is put together by summing up the Reference Numbers of the exposure and the F-stop (RN_t and RN_f). The table is shown above and indicates that both of these, the exposure and the F-stop,

have value “0” for exposure of 1 second and the aperture is F-1.0. Then, the reference number goes to 1 for the next smaller value, being ½ s for the exposure and F-1.4 for the aperture. The table continues like that, that is, reference number 2 is given to ¼ s and F-2, and so on.

EV values are obtained by summing up these reference numbers. For example, exposure of 1/30 s and F-2.8 have an equivalent EV of 8 because the reference number for 1/30 s is 5 and for F-2.8 is 3.

Here are simple formulas that I discovered (as published in issue 9 of the **CCTV focus** magazine) which will give you a very good approximation of the RN numbers with the simple use of a scientific calculator:

$$\boldsymbol{RN_f = 6.7\log(\text{F-stop})} \tag{7}$$

where F-stop is the number of the F-stop indicated by the camera light meter, that is, 5.6; 8; 11; and so on.

$$\boldsymbol{RN_t = -3.32\log t} \tag{8}$$

where t is the absolute exposure time; that is, if the camera shows 1/125, this is what you put under t. If preferred, you could use just the number 125 (we will call it T) instead of the absolute time t but the minus sign in front of the logarithm disappears, that is, the second formula becomes:

$$RN_T = 3.32\log T \tag{8a}$$

Please note: the logarithms are with base 10.

The EV is calculated by adding these two values:

$$\boldsymbol{EV = RN_f + RN_t = 6.7\log(\text{F-stop}) - 3.32\log t} \tag{9}$$

or, if T is used instead of t:

$$EV = RN_f + RN_T \tag{9a}$$

Let us work out one example.

If my camera, loaded with a 100 ISO film, shows 1/250 exposure setting and F-8, the reference numbers for F-stop and exposure can be calculated as:

$$EV = RN_f + RN_t = 6.7\log 8 - 3.32\log(1/250) = 6.7 \times 0.9 + (-3.32) \times (-2.398) = 6 + 8 = 14$$

the result is rounded.

There is a simple connection between EV values and the camera measurements described by the following equation:

$$\boldsymbol{I_{lux} = 2.5 \times 2^{(RN_f + RN_t)} = 2.5 \times 2^{EV}} \tag{10}$$

The right-hand side of the above equation is 2 to the power of the EV number and I_{lux} is obtained in luxes. For example, if the EV value of what the camera has measured is 15, this means the approximate illumination of the scene is:

$$I_{lux} = 2.5 \times 2^{15} = 81,192 \text{ lux}$$

Of course, such precision is impossible when measuring light, since many factors influence light measurement, including the reflectivity of the surrounding objects, the primary sources of light in the field of view (a light pole in the field of view will affect the average illumination dramatically), and so on. We would usually approximate the above result with 82,000 luxes.

Please note that the “dynamic range” of the light meter EV measurement may vary from camera to camera. Better cameras will have wider range. Also, do not forget to set 100 ISO when using these measurement instructions. Of course, if 200 ISO film is used, everything will be shifted for 1 EV value as the 200 ISO film is twice as sensitive as the 100; 400 ISO film is four times as sensitive, and the EV values will be shifted by two numbers. For example, if a measurement with 200 ISO film gives 16 EV, this is equivalent to 15 EV light reading with 100 ISO film.

For the end let us work out a practical example.

If my light measurement shows exposure of 1/15 s and F-2.8 (at 100 ISO film setting), this would give me:

$$EV_{(F\text{-}2.8+1/15)} = 6.7\log 2.8 - 3.32\log(1/15) = 3 + 4 = 7$$

$$I_{lux} = 2.5 \times 2^{7} = 320 \text{ lux}$$

To convert this value in foot-candles, you need to divide the value with 10, which gives around 32 foot-candles.

It should be common knowledge that a bright sunny day will give illumination of around 100,000 lux, a typical office environment would have anything between 100 and 1000 lux, a full moon night should produce around 0.1 lux, and so on.

A bright sunny day will give an EV reading of around 15 or 16, while for comfortable CCTV monitoring at night street-lights should produce an EV value of around 3, which converts to around 20 luxes.

Be aware of your light meter EV range. Many cameras have EV range between 1 and 20 EV. This indicates that the lowest light illumination you could measure with such a camera is around 5 lux. This should be sufficient for a majority of CCTV projects, but if you want to measure even lower illumination I suggest you take a look at some of the professional light meters.

Light onto an imaging device

In order to fully understand the "light issue," as seen by the camera, we need to know how much light actually falls on the imaging area.

The illumination amount at the CCD (or CMOS) chip, E_{CCD}, depends mostly on the luminance L of the object, but also on the F-stop of the lens, that is, the light-gathering ability of the lens. **The lower the F-number (bigger iris opening) the more light will get through the lens**, as will be explained later in the book. It is also proportional to the **transmittance factor τ of a lens**. Namely, depending on the quality of the glass and its manufacture, as well as the inner walls of the lens mechanics, a certain percentage of the light will be lost in the lens itself.

All of the above factors can be combined into the following relation:

$$E_{CCD} = \pi \cdot \tau \cdot L / (4 \cdot F^2) \quad [\text{lx}] \qquad (11)$$

where:

L = average luminance of the object (lux)

τ = transmittance of the lens (in percentage)

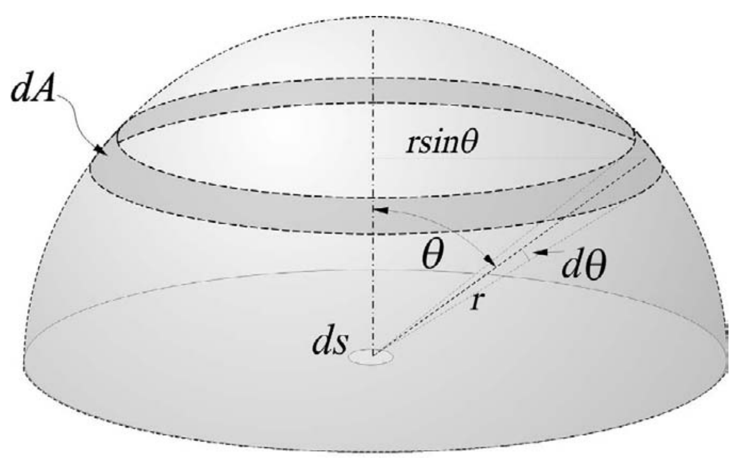
F = the actual F-stop of the lens used

$\pi = 3.14$

In the next few lines we will show how this relation is obtained and approximated, so that the technical people using these formulas can have a clear understanding of what is being assumed in order to get to formula (11). However, because these calculations involve slightly more complex mathematics, I suggest that readers with no interest, or without the background, should just directly use relation (11) as it is, knowing the values of L, τ, F, and π.

An object viewed by a camera, when lit by a light source, radiates light, more or less, in all directions, depending upon the reflectivity function. In practice, the majority of smooth surface objects can be approximated with a ***Lambertian perfectly diffusing surface***.

The flux, then, can be regarded as passing through a hemisphere of radius r and center ds. If we now consider the incremental angle $d\theta$ at an angle θ to the normal, the flux occupying the volume of a revolution swept out by the angle $d\theta$ passes through



Lambertian diffusing surface

an annular ring on the surface of the sphere, with width $rd\theta$ and circumference $2\pi r\sin\theta$.

This elementary surface area is given by:

$$dA = 2\pi r^2 \sin\theta \, d\theta \qquad (12)$$

and hence the solid angle ω that it subtends at the center of the sphere is given by:

$$\omega = dA / r^2 = 2\pi \, r^2 \sin\theta \, d\theta / r^2 = 2\pi \sin\theta \, d\theta \quad \text{[steradian]} \qquad (13)$$

Since for a Lambert surface the luminous intensity (flux per steradian) in a given direction falls as the cosine of the angle to the normal, we have the luminous intensity of the whole surface in the direction of the normal as I, and then at an angle θ it will be given with $I \cos\theta$.

The luminous intensity dI of a small area ds will be given by:

$$dI = I \cos\theta \, ds / s \quad \text{[lumens/steradian = candelas]} \qquad (14)$$

Since I/s is the actual luminance L in the perpendicular direction, the above relation becomes:

$$dI = L \cos\theta \, ds \qquad \text{[cd]} \qquad (15)$$

The elementary flux dF is equal to the elementary intensity dI times the solid angle:

$$dF = L \cos\theta \, ds \, 2\pi \sin\theta \, d\theta \quad \text{[lm]} \qquad (16)$$

The total light emitted into a cone of an angle θ can be found by integration from 0 to θ:

$$F = \int 2 \, \pi \, L ds \sin\theta \cos\theta \, d\theta = \pi \, L \, ds \sin^2\theta \qquad \text{[lm]} \qquad (17)$$

If we want to find the total flux radiated in all directions, we have to put 90° for the angle θ so that the total flux emitted in all directions will then be:

$$F_t = \pi \, L \, ds \qquad \text{[lm]} \qquad (18)$$

Now, if we have to calculate the flux emitted into a solid angle smaller than 90°, as may be the case when a camera is viewing an object, the total flux F_o is given by the formula:

$$F_o = \pi \, L \, ds_o \sin^2\theta_o \qquad \text{[lm]} \qquad (19)$$

If the lens transmission factor is τ, then the flux falling on the CCD or CMOS chip plane is:

$$F_{CCD} = F_o \, \tau = \pi \, \tau \, L \, ds_o \sin^2\theta_o \qquad \text{[lm]} \qquad (20)$$

The illumination of the imaging chip would be flux divided by the imaging chip area ds_{CCD}, that is,

$$E_{CCD} = \pi \, \tau \, L \sin^2\theta_o \, ds_o / ds_{CCD} \qquad \text{[lx]} \qquad (21)$$

The ratio (ds_{CCD} /ds_o) ,which is inverse in the preceding formula, is also known as the ***magnification ratio of a lens m***. The magnification ratio can also be approximated as a ratio between the focal length of the lens and the distance to the object.

$$m = (f/D)^2 = ds_{CCD} / ds_o \qquad (22)$$

When we replace (18) in (17), it becomes:

$$E_{CCD} = \pi \, \tau \, L \sin^2\theta_o (D/f)^2 \quad [lx] \qquad (23)$$

We need to introduce here another ratio in a lens (*d/f*), which is also known as the lens F-stop (this will be explained in more detail in Chapter 3). For objects at a reasonably long distance from the camera (again, this is typical in CCTV) we get the following to be true:

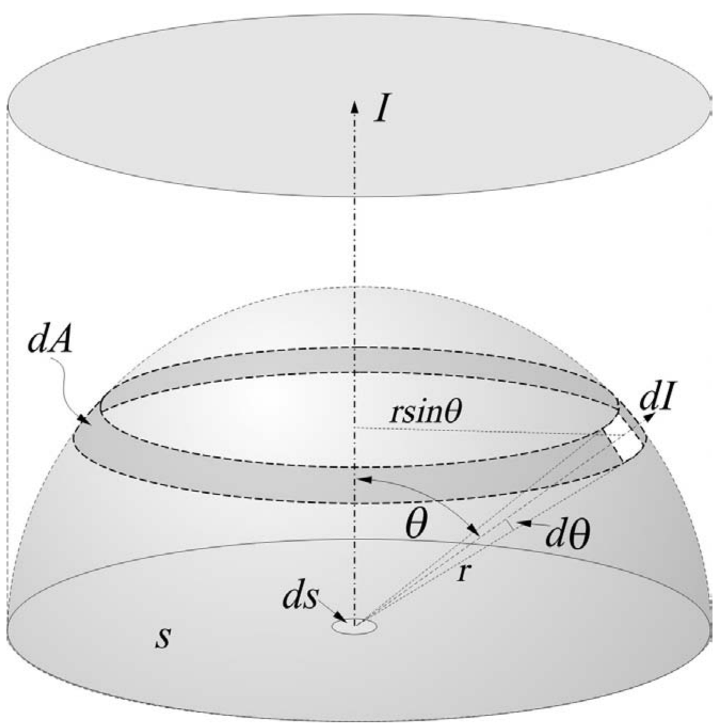
$$\text{tang } \theta_o = d/2D = \sin \theta_o / \cos \theta_o = \sin \theta_o \qquad (24)$$

Such an approximation can be made because for very long distance to objects the angle θ_o is very small and the cosine of such angles is very close to 1.

So, we can substitute $\sin^2 \theta_o$ with $(d/2D)^2$, and thus equation (19) becomes:

$$E_{CCD} = \pi \, \tau \, L \, (d/2D)^2 (D/f)^2 \quad [lx] \qquad (25)$$

If we sort this out we will have:



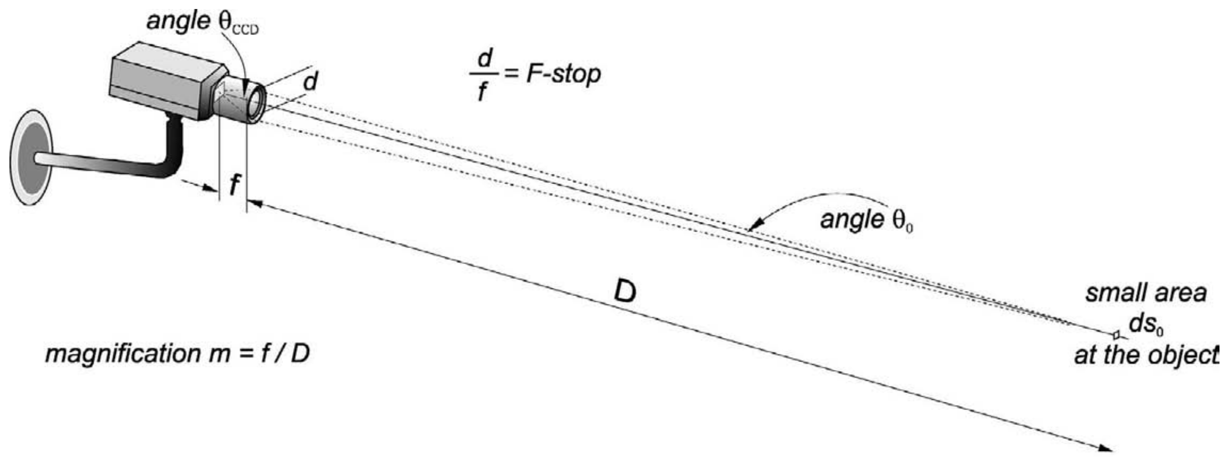
Calculating the light radiation with Lambertian diffused light source

$$E_{CCD} = \pi\,\tau\,L\,(d^2/4D^2)\,(D^2/f^2) = \tau\,\pi\,L\,(d^2/4f^2) \qquad (26)$$

And finally this becomes the simplified formula for calculating the light amount falling onto an imaging device:

$$E_{CCD} = \pi\,\tau\,L/(4\,F^2) \quad [\text{lx}] \qquad (27)$$

This is a very useful formula because it uses only two variables (the luminance of an object and the lens F-stop) to calculate the approximate illumination that falls onto an imaging chip. But the approximation we made should not be forgotten, so it should be used only for rough calculations and in cases that correspond to the conditions of the approximation, that is, the camera looking at an object with diffused light, similar to Lambertian source (most of the real-life objects are like that, except mirrors and surfaces alike), at a reasonably long distance relative to its focal length lens. Usually, the lens transmittance factor τ ranges between 0.75 and 0.95. If you do not have the correct number from your lens manufacturer, for calculation purposes a realistic transmittance factor can be taken to be 0.8.



Calculating the amount of light falling onto a CCD chip

Let us work out an example. If the light at the object plane is around 300 lx, as in an average office area (this would be E_{object}), the luminance can be found using the reflection coefficient of the surrounding objects, that is, $L = \rho\,E_{object}$. As mentioned earlier, reflection factors vary substantially with various objects, but we will not be far from a real office situation if we assume 50%. If the lens we are using has an iris setting of, say, F-16, the illumination at the CCD plane will be approximately $E_{CCD} = 0.8 \cdot 3.14 \cdot 300 \cdot 0.5 / (4 \cdot 256) = 0.36$ lx. This, combined with the camera's automatic gain control (AGC), is a realistic illumination for a CCD chip plane for a full video signal. If, however, the lens iris is set to F-1.4, for example, the illumination of the CCD plane will be approximately 48 lx (using relation (17)). This is a far higher value than the CCD chip needs, and in practice it can only produce a recognizable video if an auto iris lens is used, or if the camera has an electronic (or CCD) iris builtin. If a manual iris lens is used with an F-1.4 and the camera's AGC is set to off, 48 lx at the chip will produce a saturated, or washed-out, white image.

A very basic rule of thumb is that even a lens with the lowest F-number attenuates the light for a factor of 10 +. The higher the F-number, the lower the amount of light that reaches the CCD plane. In fact,

it is inverse proportional to the square of the F-number.

With the above conclusions we are actually tapping into a very interesting question raised with CCD cameras (especially B/W, i.e., cameras without infrared cut filters): If the object illumination is as at a full sunny day (approximately 100,000 lx), the F-number has to be very high in order to “stop-down” the light as required by the CCD chip. This is in the vicinity of 0.1 ~ 0.3 lx (or close) for a full video. Such an F-number is actually so high that it requires the attenuation of the lens to be in the order of over 1,000,000 times. Using the approximated formula (27), assuming the same values for $\tau = 0.8$, $\rho = 0.5$, and assuming the camera CCD chip requires 0.2 lx for a 1 V_{pp} signal, we will get an F-number of 886.

This is an extraordinarily high F-number to be achieved by mechanical means (leaves shutter). The precision of the leaves’ movement is limited, and, more importantly, an unwanted optical effect called a Fresnel Edge Refraction becomes noticeable with small iris openings. This means that, in practice, **very high F-stops cannot be achieved by using just mechanical methods**. So, special optical neutral density (ND) filters are used to “help” the leaves shutter achieve high F-stops as required by the sensitive CCD chips. The inferior optical precision of such filters could make an image appear less sharp in very bright light and yet quite good in lower or normal light conditions.

Colors in television

Colors are a very important and complex issue in CCTV. Although some people still prefer monochrome (B/W) cameras because of their greater sensitivity and response to the infrared invisible spectrum, color cameras have become widely accepted. In the last few years (since the previous edition of this book in 1999), an increasing number of camera manufacturers are offering so called Day/Night cameras, which switch to B/W mode automatically when the light level falls below certain range.

Color offers valuable additional information on the objects being monitored. More importantly, the human eye captures color information quicker than the fine details of an object. The drawback of using color cameras is their not so good performance in low-light levels. The reason for this is the usage of the optical infrared cut filter on the color CCD chips, which attenuate the light and eliminate the invisible infrared portion of the projected image (more on this in Chapter 5). With the ever improving CCD technology, however, the color camera minimum illumination performance has improved dramatically. From 10 lx @ F1.4 at the object, of a few years ago, we now have cameras that can see down to less than 1 lx @ F1.4 at the object, or even lower.

As already explained under the ***Light Basics and the Human Eye*** section which is in this chapter, the colors we see are actually various wavelengths of light. When we see red, for example, it is a wavelength reflected from a red object when white light is shone on it. Black absorbs almost all wavelengths, whereas white reflects most of them.

The science of colors is very complex and becomes even more complicated when the natural colors around us are reproduced by the phosphor coating of the cathode ray tubes (CRTs).

The concept of producing colors in television is by ***additive mixing*** of three primary color phosphor dots next to each other. These are tiny dots, representing parts of a mask that is on the inside of a monitor's CRT. A similar concept of mixing color is used on Plasma and LCD monitors. We are going to explain CRTs in more detail because they are most common in CCTV.

The actual color mixing happens when we view the monitor from the viewing distance (usually a meter or a couple of meters) and the resultant color of each of the three dots appears in our eyes.

The additive color mixing in television is opposite to the one in painting and printing technology, where colors are obtained by ***subtractive mixing***.

In additive mixing, light is produced by the phosphor coating of a CRT and adding colors makes the resultant color brighter. Therefore, to get white, all three colors need to be present with their corresponding amounts. Resultant colors are obtained by adding and therefore the name additive.

With subtractive mixing of colors, when we use paper or acrylic as a secondary source of light (reflected), colors are mixed in our eye after they are reflected from the surface. If we mix (add) all the primary colors, we produce darker colors instead of brighter. The colors are mixed by reflected light, whose color is defined by the pigment, which absorbs (subtracts) the wavelength its surface has.

Getting back to television, three colors, as mentioned, are used as primary colors: red, green, and blue, usually referred to as RGB.

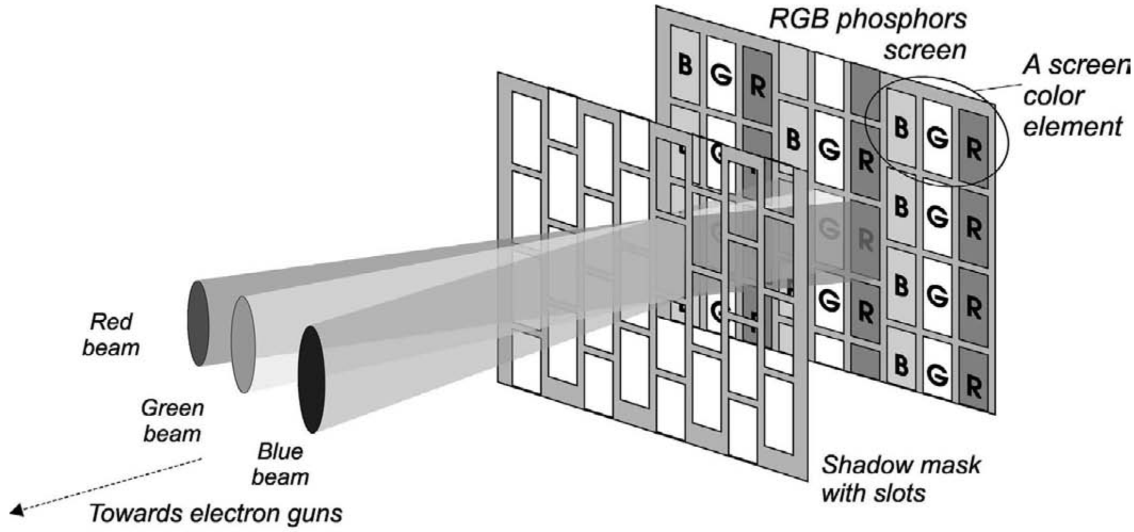
Television theory and experiments have shown that with these three primary colors **most** of the natural colors can be represented (but not all).

Obviously, there are **three different phosphor coatings** inside the color CRT, each of which radiates its own color when bombarded by the electron beam.

The three primary phosphor coatings have different luminosity properties, which means **equal beam intensity produces unequal brightness**. In order to compensate for these discrepancies of the primary phosphors, every color TV and monitor has a special matrix circuit that multiplies each of the color channels with a different compensating number. This can be shown by the very well-known color TV luminance equation, which is electronically applied to the three primary signals in the CRT:



Color images on TV are made up of three phosphor mosaics (RGB).



The RGB shadow mask

$$L_{screen} = 0.3R + 0.59G + 0.11B \quad (28)$$

The blue phosphor produces more light than the other two; it therefore has to be multiplied by 0.11 in order to reduce the luminance to be equal to the other two components.

In this book we will not go much deeper into the theory of colors in television, for it requires a book on its own. It is important, however, for the reader to appreciate the complexity of the issue and accept that all colors as seen on TV are obtained by visual additive mixing of the three primary colors of the CRT phosphor: red, green, and blue.

Color temperatures and light sources

Very often in television, CCTV, and photography, the term *color temperature* is used when talking about light sources. ***Color temperature*** refers to the temperature to which an imaginary perfectly black body is heated and consequently produces light.

The theory of physics states that **the spectrum of light generated by heating is mostly dependent on the temperature of the body and *not on the material***. This very important statement has been proven by the physicist Max Planck whose formula explains the relationship between the peak wavelengths radiated and the temperature to which the body is heated:

$$\lambda_m = 2896/T \quad (29)$$

In the above relation λ_m is the wavelength and T is the temperature in Kelvin degrees.

From the diagram on the next page it can be noted that the peaks for different temperatures are outside of the visible spectrum, that is, in the infrared region. For tungsten (wolfram) filament light, the working color temperature is around 3000° K, and more than three-quarters of the energy is radiated in the

infrared region in the form of heat. Heat is nothing more than infrared light. Higher temperatures for tungsten lights cannot be used because the melting point of wolfram is around 3500° K. Increasing the temperature to more than 2800° K will dramatically shorten the lifetime of the tungsten light. In today's tungsten globes, the air is extracted from inside the bulb in order to minimize the burning of the filament. Tungsten light is good for B/W cameras, since they are more sensitive to the infrared portion of the spectrum. Color cameras have to be compensated for the yellow/reddish color produced by a 2800° K light globe typically found in domestic lighting.

For accurate testing of cameras, very often a light source of around 3200º K is specified. Such lights can be purchased from professional photographic shops, but there is a general rule of thumb that can be used to calculate the color temperature and the lumens produced by such a light source:



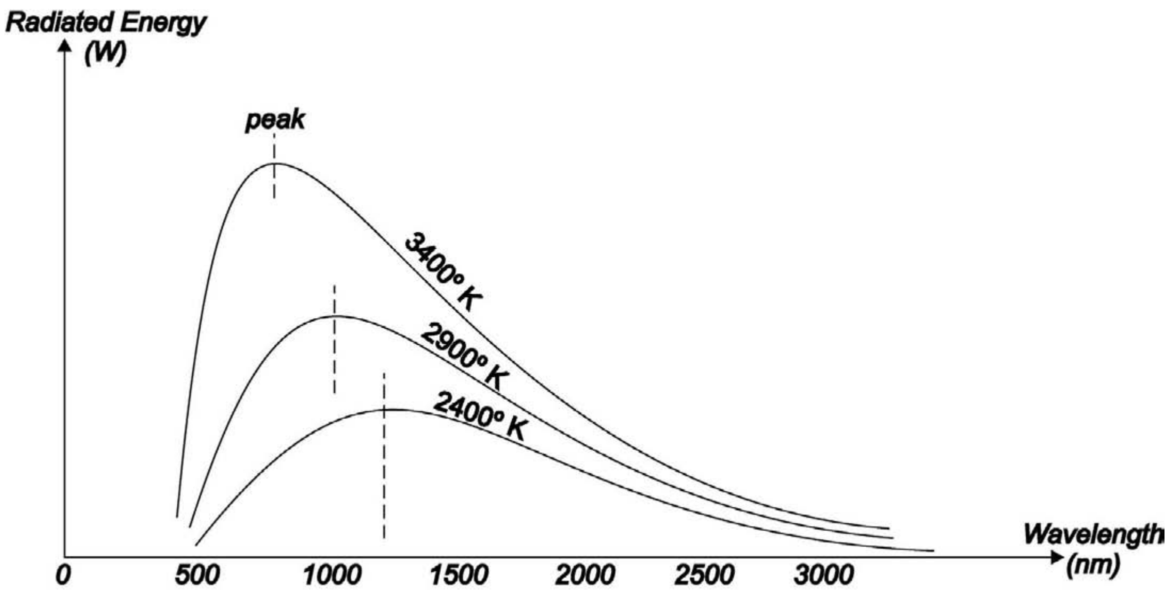
A typical photographic tungsten light source with 3200º K

500W tungsten => 3200º K (approximately 27 lumens/watt)

200W tungsten => 2980º K (approximately 17.5 lumens/watt)

75W tungsten => 2820º K (approximately 15.4 lumens/watt)

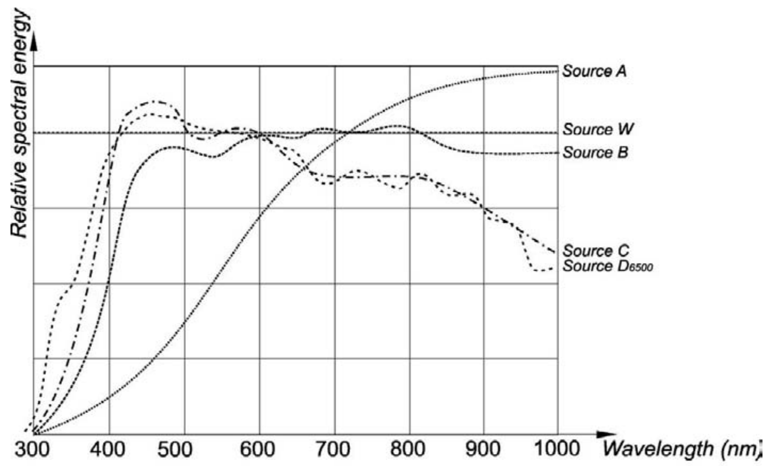
It is known that a tungsten light source produces a yellowish image on a photographic film camera. In order to compensate for this blue optical filters (complementary color) can be inserted on the lens itself. Electronic cameras (CCTV and TV) compensate the yellowish color shift electronically by changing the primary colors' information by a certain percentage. Most of the CCTV cameras have the so-called automatic white balance (AWB) circuitry that adjusts its color temperature automatically upon powering the camera



Spectral characteristic of a black body at various temperatures

up and seeing a larger white area. A more advanced camera can readjust such a white balance "on the fly," that is, without powering the camera down and up again. This white balance is usually referred to as automatic tracking white (ATW) and is very practical especially when using pan/tilt/zoom (PTZ) cameras covering a larger area, part of which might be an area with tungsten light, for example, and another with neon light.

The sun, as a natural source of light, has a very high physical body temperature, but the equivalent light color temperature that we get on the Earth's surface varies with the time of the day and weather conditions. This is due to the light reflection and refraction through the atmosphere. As shown in the table of ***Color temperatures of various light sources*** on the next page, on a clear day, at noon, the color temperature reaches over 20,000° K, while on a cloudy day it drops down to nearly 6000° K. This is why photographs taken at sunset hours appear reddish. The lower the color temperature, the redder the pictures will appear, and the higher it is, the bluer they will appear.



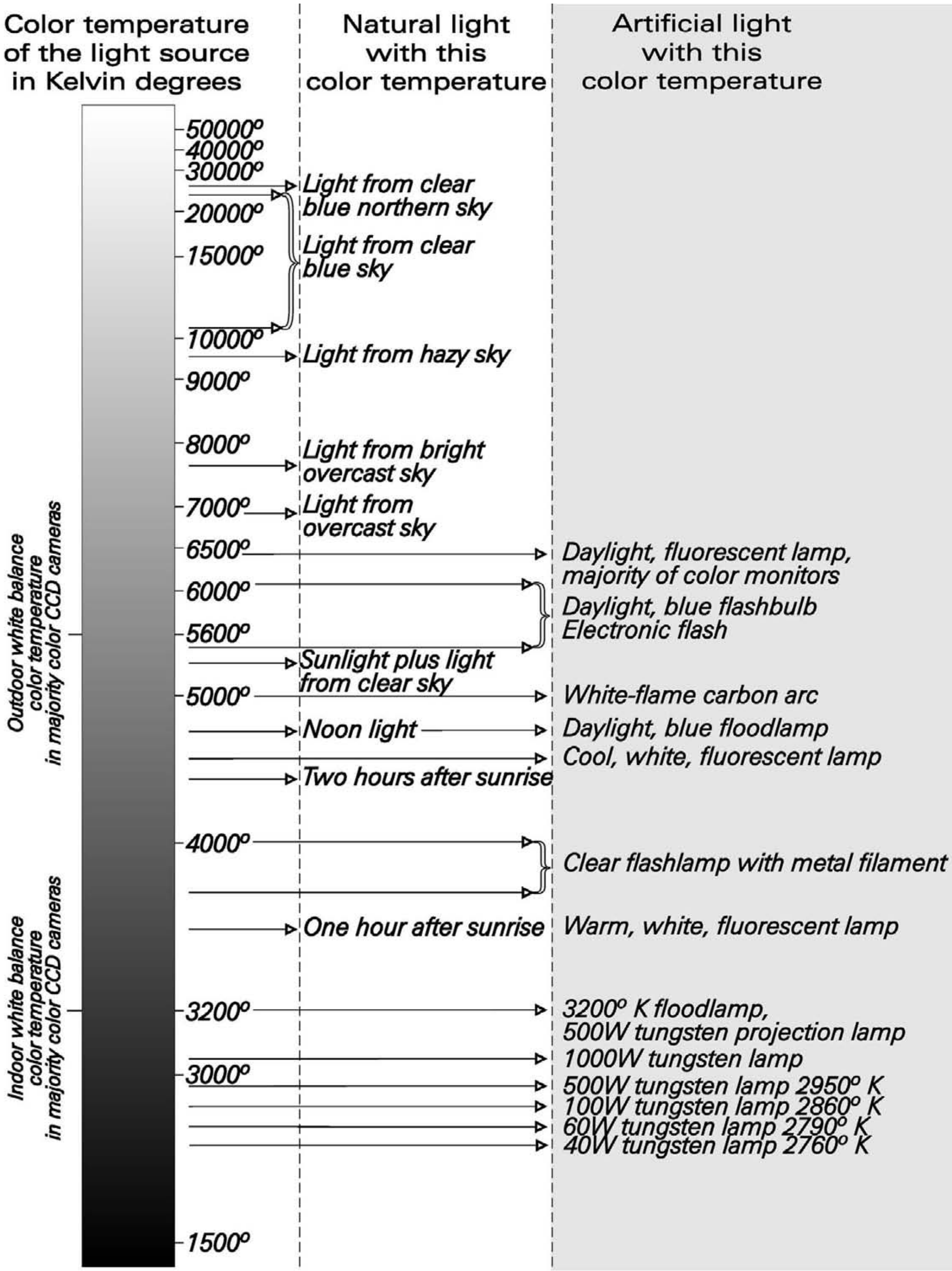
Standard light sources

Artificial sources of light have various color temperatures, depending on the source. The above-mentioned formula (29) applies to heat sources only, that is, sources of light where a metal is heated up to a high temperature. There are, however, gas sources of light, where light generation is of a different nature. Neon lights, or mercury vapor lights, for example, generate light when an electromagnetic field is applied to them. The atoms are excited by an energy sufficient to cause certain atom reactions, and energy is released in the form of light. **This light is of a discrete character due to the quantum behavior of the atoms**. The position(s) of the wavelength(s) will depend on the gas used. Some of the glass tubes used with such gases are coated on the inside with a fluorescent powder that might absorb certain primary wavelengths and then regenerate a continuous secondary spectrum of visible light.

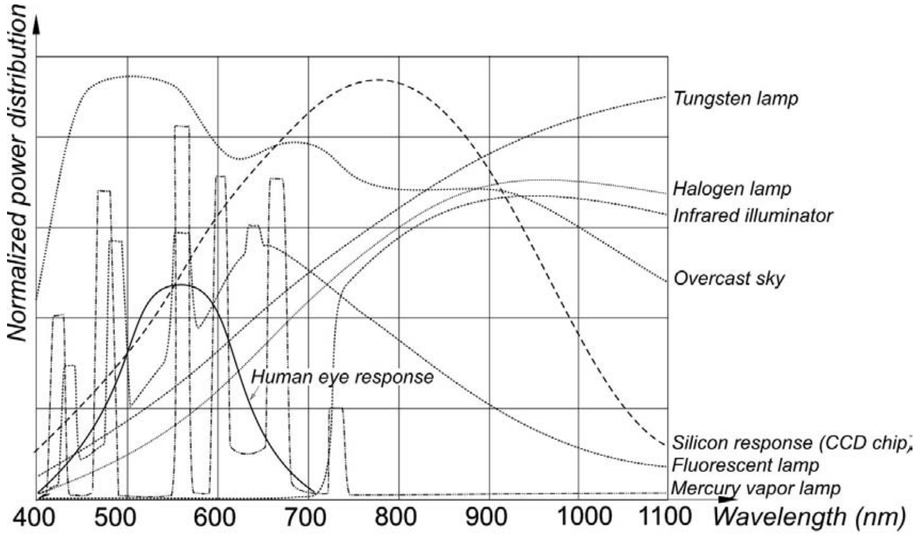
Gas sources can also be described by their color temperature; only in this case we use a so-called ***correlational color temperature***.

For the purposes of having a reference point and correct color reproduction, standard sources of white light have been defined. There are a few definitions (standards) used in practice. These standard sources of white light are marked as **A, B, C, D**$_{6500}$, and **W.**

Source **A** is the most natural standard as it represents a tungsten (wolfram) light globe, filled with some gas to reduce burning of the filament. That is why most of the other later developed standards are based on source A. As mentioned earlier, at a certain temperature, the characteristics of a wolfram



Color temperatures of various light sources



Spectral energy dissipation of various light sources

light coincide a great deal with the radiation of a black body. This means **the spectrum of source A, at a certain temperature, can be represented by only *one* detail – the temperature, which is equal to the temperature of the black body.** To be precise, the real temperature of the wolfram and the black body at which their spectrums are supposed to be identical is not exactly the same. The black body is hotter by approximately 50° K. The spectrum characteristic of the standard source A is defined as a color temperature of 2854° K, while the real filament temperature is approximately 2800° K. This is an insignificant difference, however, and the theoretical approximation is valid and accepted as a descriptive factor for the color temperature of such sources.

Standard source **B** radiates white light, similar to direct sunlight at noon. Source B can be obtained by filtering the light from source A through a special light filter.

Similarly, by using another type of light filter, standard light source **C** can be obtained. The characteristics of sources B and C cannot be represented with the color temperature of a black body, as can be seen on the diagram above. However, if the color of a black body looks similar to either of the sources B or C, we use the term ***correlational color temperature***. So, the correlational temperature of source B is 4880° K, and for source C it is 6740° K.

The ***International Committee for Light*** **(CIE)** in 1965 suggested a new standard source of light, which is supposed to represent an average daylight color temperature and is represented as the **D** standard. The recommended correlational color temperature for the standard D is 6500° K, so the standard is marked as $\mathbf{D}_{6500}$. This source of light cannot be obtained by modifying source A, but its spectral characteristic can be approximated with some other physical sources, as is the case with a correct mixture of the three phosphor coatings of the CRT of a color monitor. An important fact to remember is that $\mathbf{D}_{6500}$ is often used as a reference for color monitors.

Last, there is another, fictitious, light source with a uniform distribution of radiated energy, which looks like a flat horizontal line. This is only for calculating purposes, and the code of this light source is **W**. The human eye adapts to the color temperature differences quite easily, and our brain automatically compensates the color variation due to different light sources. Film emulsions, tubes, and camera CCD chips are a bit different. When using a film camera, special films or optical filters have to be used if color temperature needs to be corrected. With TV cameras this is achieved by electronic compensation,

which can be either manual or automatic.

Finally, and as already mentioned, do not forget to take into account the color temperature of the monitor screen. The majority of CRTs are 6500° K, but some of them might have higher (9300° K) or even lower (5600° K) temperatures.

Eye persistence

For us in CCTV, it is very important to know how the human eye works, and as we will see further in the text, we actually use an anomaly of the human eye in order to "cheat" the brain into thinking we see "motion pictures." This anomaly is the ***persistence*** of the human eye.

Eye persistence is the most important "eye defect" used in cinematography and television. The eye does not react instantly to the changes of light intensity. There is a delay of more than a few milliseconds during which the brain gets the information about the object we are watching. This delay increases with an increase of the object's illumination. Not all parts of the retina have equal persistency. The central area around the fovea has longer persistency. Eye persistence also depends on the spectral characteristics of the light source, that is, its color and brightness.

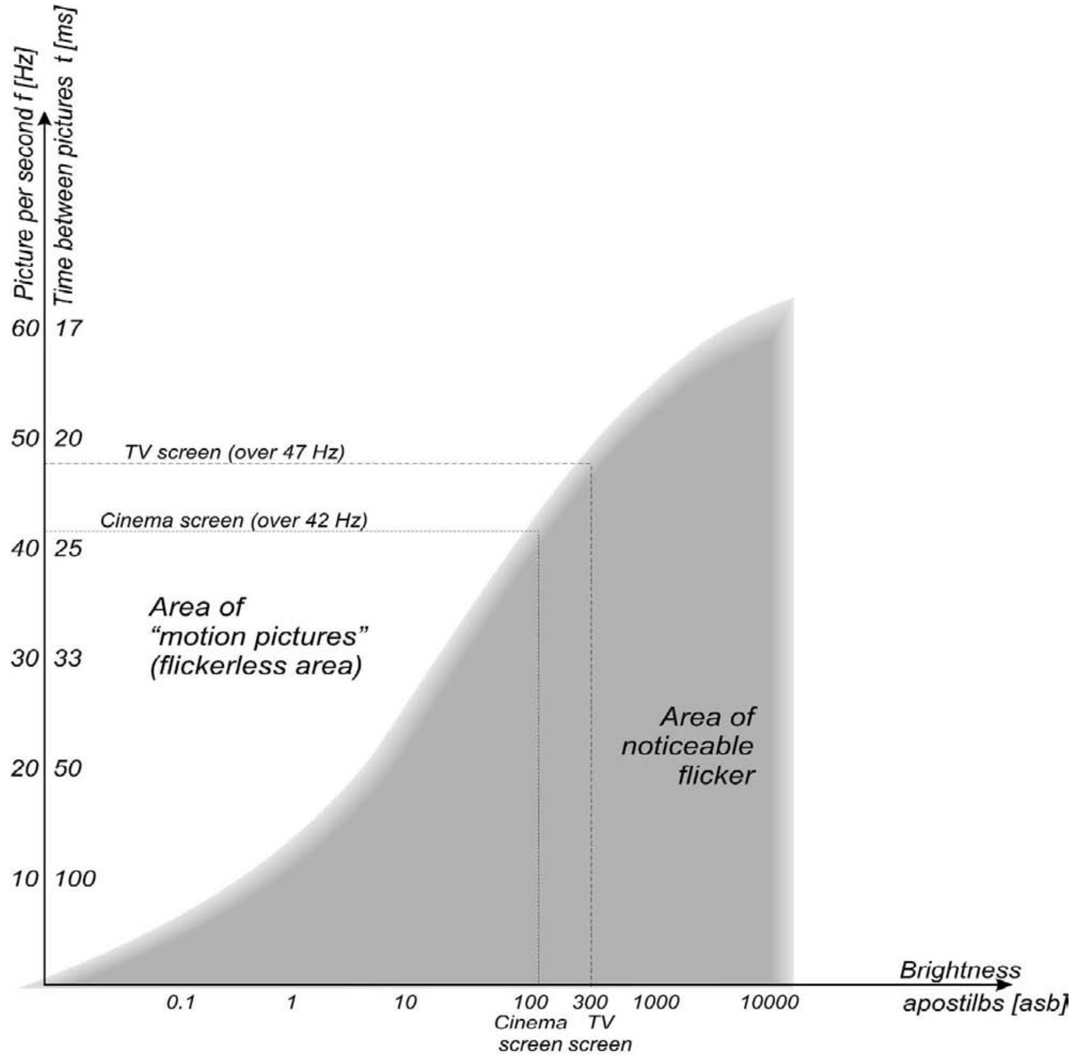
The above eye deficiency is very important for the concept of motion pictures. As can be seen on the graph on the next page, the persistence depends very much on the intensity of the light, or the brightness of the area we are looking at. The brighter the area is, the faster we have to change the pictures if we do not want to notice the flicker. The first movies from the beginning of the twentieth century, cartoons, and even the cartoon "flipping books" we used to play with as kids are based on the concept of persistency.

When pictures with a logical consecutiveness are played in front of our eyes at a speed equal to or faster than the persistency of the eye, we will see continuous moving pictures even though the pictures are **still,** individually.

A movie camera records images with a speed of 24 pictures/second. This is usually enough for the film to be projected with a very low light intensity projector, as in the beginning of the cinema revolution. For bigger audiences, bigger and stronger light projectors were needed, as well as brighter screens (as we have today). So it was obvious that the initial 24 pic/s speed needed increasing.

From a photographic point of view, which is very similar to the cinematographic one, it is impractical to increase the frame rate of the movie camera from 24 pic/s to a higher rate because the exposure time of every film frame will have to be shortened. To achieve that, the film either has to be of a higher sensitivity, which is reflected in the bigger grain structure of the film, or the iris of the lens needs to be opened more, which results in not-so-good pictures at lower light levels as well as a reduced depth of field.

Neither of these two suggestions was acceptable for cinematographers, so the solution was found in increasing the projection frequency (not the recording) from 24 to 48 with a simple but clever design. This was achieved with the so-called Maltese Cross shutter, which is a circular blade that is cut in the



Persistence curve of the human eye

shape of the Maltese Cross. This rotates in front of the projection light bulb and not only blocks the light when the film moves from one frame to another (so the viewers do not see black lines between each film frame), but it also interrupts the projection while the frame is stationary (for the duration of 1/24 s) and produces two flashes of the same frame. As a result, we have a projection of 48 frames/s, which is flicker-free to the eye. Clearly, there are only 24 **different** pictures recorded each second, but the cross produces 48 of the same, and our brain perceives flickerless continuous moving pictures.

Television uses the same principles of eye persistence to achieve the illusion of motion by using so-called interlaced scanning. The conceptual difference is in composing the images not by using a light projector through a celluloid film, but with **electronic scanning** of a CRT screen. In television, still images are created by scanning, where a picture is formed line by line, in the same manner as when reading a book, from left to right and from top to bottom. These principles shall be explained in more detail later in the book.

It is important for the reader to understand that **television also projects static images which, when**

displayed fast enough, are seen as "motion pictures." Whether this is done by interlaced or progressive scanning is irrelevant at this stage, but it should be noted that the television technology today is at such a stage that it can use improved "tricks" for the eye's motion illusion to be even better.

In the world today there are three basic television systems that differ in the number of pictures per second, the number of lines each picture is composed of, and the method of color encoding. But in all of them the concept of producing motion is the same.

PAL: 625 scanning lines/50 interlaced pictures per second

NTSC: 525 scanning lines/60 interlaced pictures per second

SECAM: 625 scanning lines (used to be 819)/50 interlaced pictures per second

Although different in the number of scanning lines and pictures per second, the general concept is the same from the point of view of composing picture frames field by field and line by line, scanning them at a fast rate to make use of the persistency concept as in film.

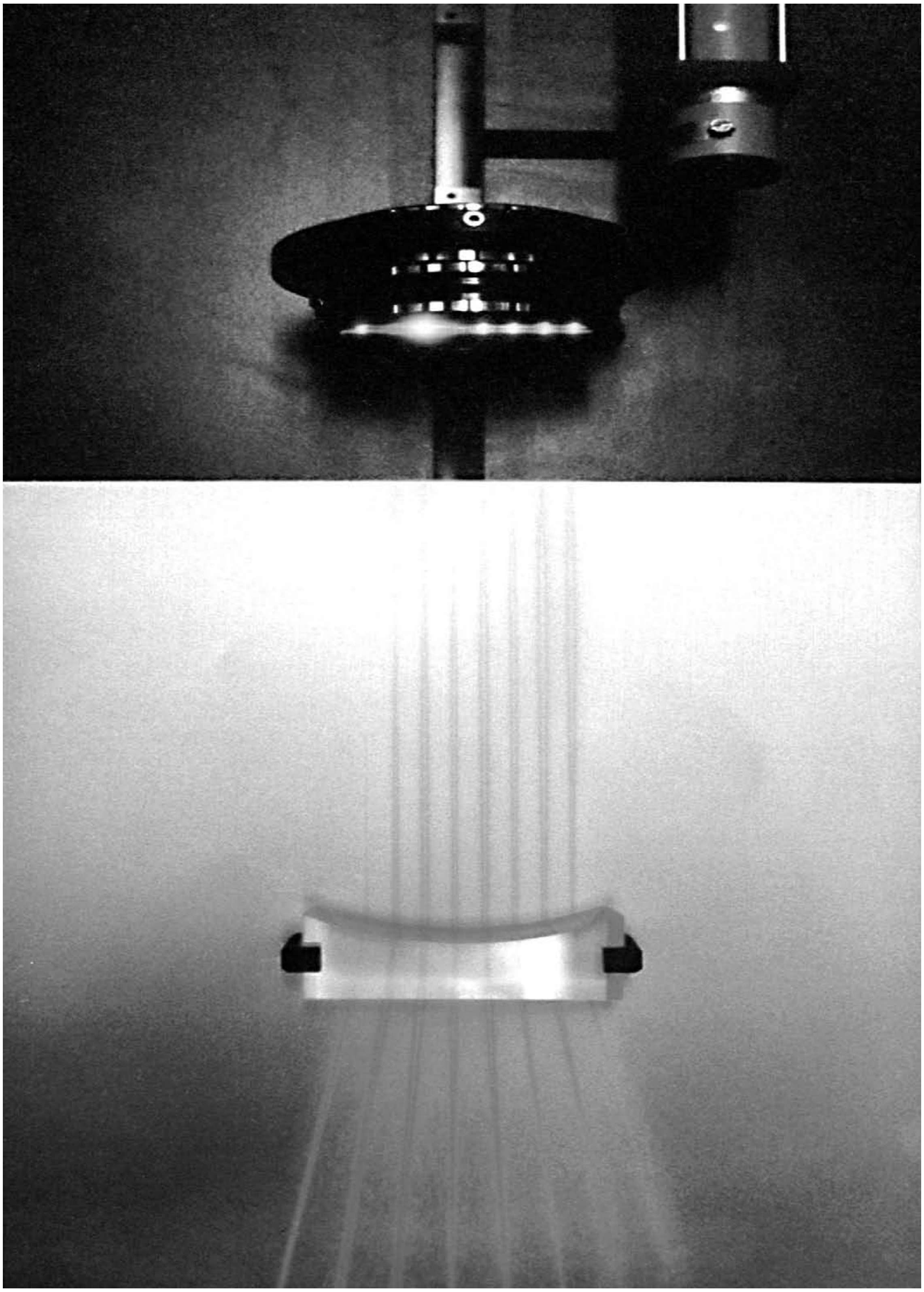
The NTSC's (National Television Systems Commitee) 525-line, 30-frames-per-second system is shared primarily by the United States, Canada, Greenland, Mexico, Cuba, Panama, Japan, the Philippines, Puerto Rico, and most of South America. The NTSC standard was first developed for black and white (monochrome) television in 1941. The first color TV broadcast system was implemented in the United States in 1953.

More than half of the countries in the world use one of two 625-line, 25-frame systems: the PAL (phase alternating line) system or the SECAM (sequential couleur avec memoire or sequential color with memory) system.

The PAL standard was introduced in the early 1960s and implemented in most European countries, Australia, New Zealand, China, India, and many countries in Africa and the Middle East. The PAL standard utilizes a wider channel bandwidth than NTSC, which allows for better picture quality. Also, the color encoding in PAL, being designed after the introduction of NTSC, offers more accurate color reproduction and better immunity to noise.

The SECAM standard was introduced in the early 1960s and implemented in France; it is used in parts of Europe, including countries in and around the former Soviet Union. SECAM uses the same bandwidth as PAL but transmits the color information sequentially. The extra 100 lines in the SECAM and PAL systems add significant detail and clarity to the video picture, but the 50 fields per second (compared to 60 fields in the NTSC system) means that a slight flicker can sometimes be noticed. It is interesting to note that although Russia, for example, uses SECAM for broadcast TV, the CCTV industry there uses PAL.

With the introduction of the new digital TV standards (DTV) it is possible to have both interlaced and progressive scanning. These are usually denominated with a lower case "i" or "p" next to the standard. For example, "1080i" refers to HDTV with 1920 × 1080 pixels and interlaced scanning.



3. Optics in CCTV

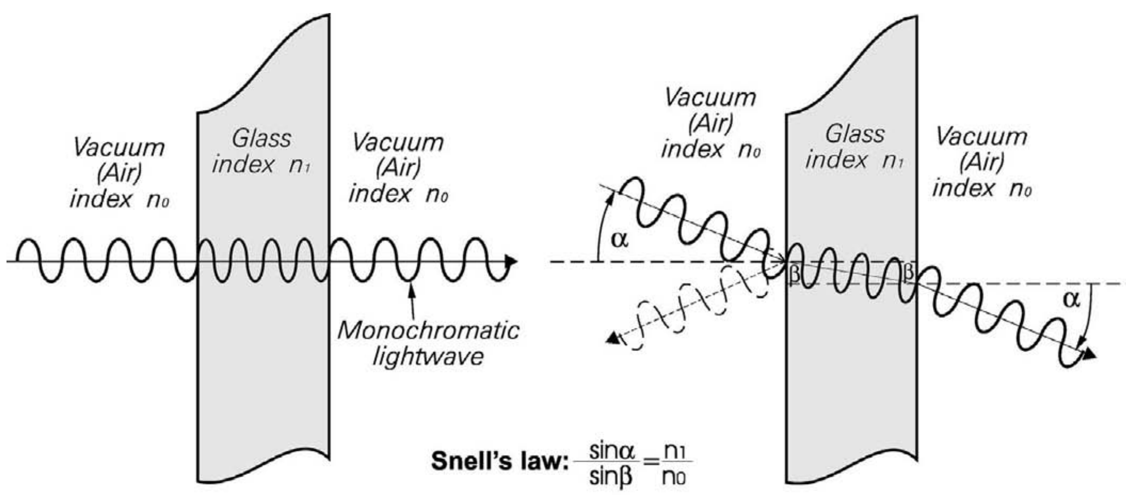
Some people take optics quality in CCTV for granted. With the camera resolution development, as well as the miniaturization of CCD chips, we are coming closer to the limits of optical resolution and we need to know a bit more than an average technician. This chapter discusses, again in a simplified way, the most common optical terms, concepts, and products used in CCTV.

Refraction

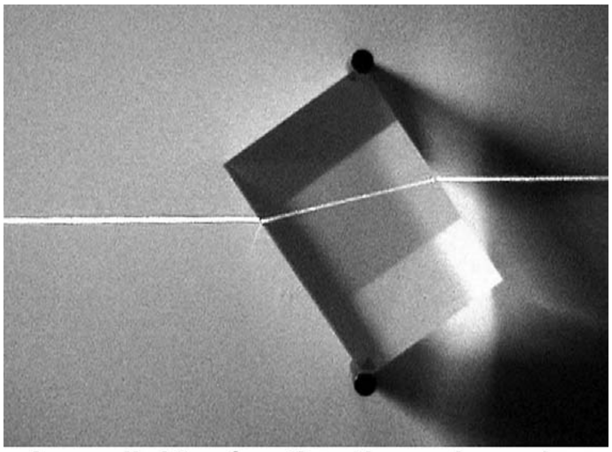
The very first and basic concept we have to understand is the concept of ***refraction*** and ***reflection***.

When a light ray traveling through air or a vacuum enters a denser medium, like glass or water, it reduces its speed by a factor ***n*** (always bigger than 1) known as the ***index of refraction***. Different media (which are transparent to light) have different indices of refraction. For example, the speed of light in air is 300,000 km/s (almost the same as in a vacuum). If a light ray enters glass, for example, which has an index of 1.5, the speed is reduced to 200,000 km/s.

According to the wave theory of light, the reduction of the light speed is reflected in its shortened wavelength. This phenomenon represents the base of the concept of refraction. If a light ray enters the glass perpendicularly, the wavelength of the light ray shortens, but when the ray exits the glass it resumes to normal speed, that is, returns to the original "air wavelength" and continues its travel in the same direction. If, however, the light ray enters the glass at any angle other than the perpendicular, interesting things happen: the light ray (considered to be of a wave nature in this case) has a front that does not enter the glass media at the same time (because it comes under an angle). The parts of the front that enter the glass first are "slowed down" first. The end result is the refraction of the light ray; the ray does not continue in the same direction but deflects slightly. This deviation depends on the density of the media.



Light refraction and Snell's law



Laser light refraction through a prism

The denser the media – that is, the higher the index of refraction – the greater the inclination of the original direction.

There is a very simple relation between the angles of incidence and refraction and indices of refraction between the two different media. This relation was discovered by the Dutch physicist Willebrord Snell in the early seventeenth century. By using a very simple calculation, we can determine the angles of refraction in various media. As we shall see later on, the same concepts are used when calculating the angles of total reflection and numerical aperture in fiber optics.

The basics of refraction are graphically explained in the diagram on the previous page, where it is assumed a monochromatic (single frequency) light ray enters the glass. The bottom drawing also shows that a percentage of the incident light is always reflected back into air (or vacuum); in the case of glass this percentage is very small.

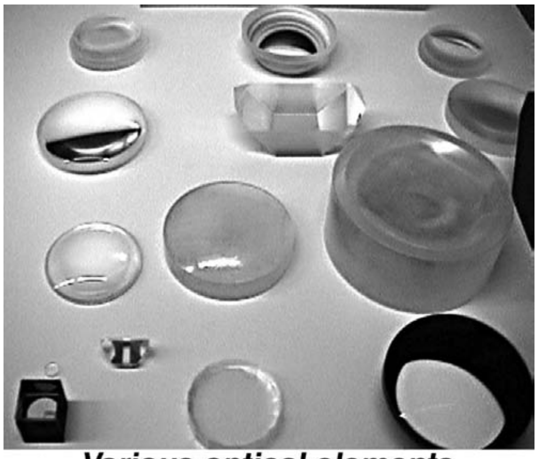
The refraction and reflection theories will be used in the next headings when explaining lens and fiber optics concepts.

Lenses as optical elements

There are many optical components, but the two basic types of lenses are ***convex*** and ***concave***. The first one, convex, has a positive focal length; that is, the focus is real, and we usually call it a magnifying glass, since it appears to magnify the objects. The second one, concave, has a negative focal length; the focus is virtual, and it appears to reduce the objects.

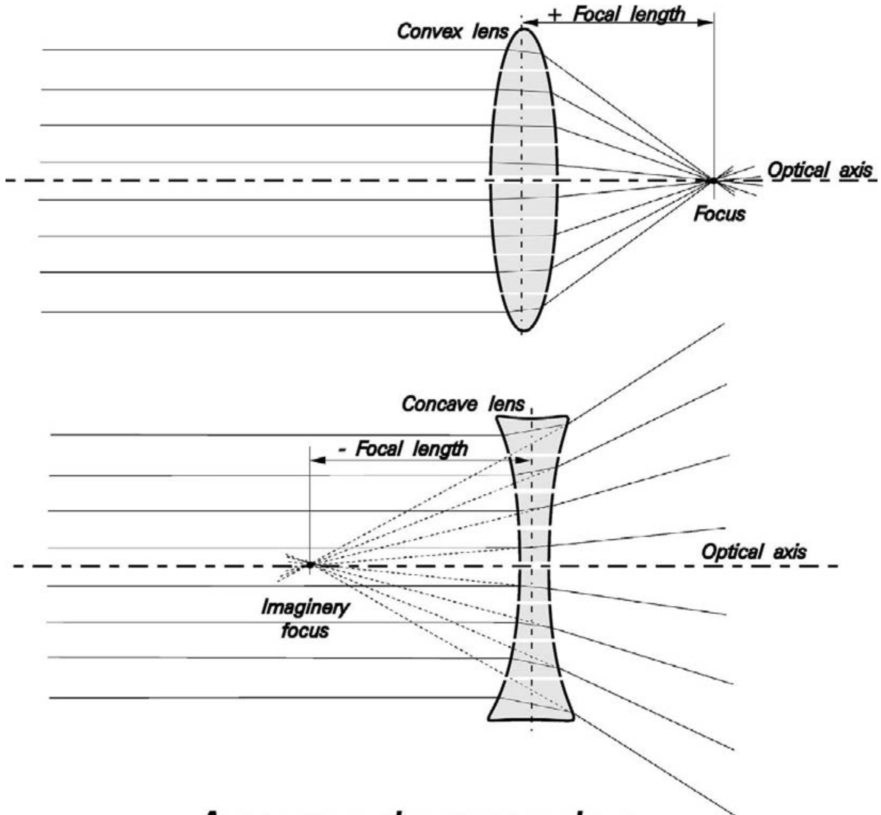
Every lens has the following important parameters:

- Optical plane (a plane passing through the center of the lens)
- Optical axis (an axis perpendicular to the center of the optical plane)
- Focus (a point where rays falling parallel to the optical axis converge)
- Focal length (the distance between the optical plane and the focus, in meters)
- Diopter (an inverse value of the focal length, where the focal length is stated in meters)



Various optical elements

In respect to the physical size and the type of surface of the lens, there are many different types, such as plano-convex, convex-concave, and plano-concave. The name describes the physical appearance of the lens, where ***plano*** means one of the two surfaces is a plane.



A convex and a concave lens

Different types of lenses have been put together in order to correct various distortions (aberrations) caused by different factors.

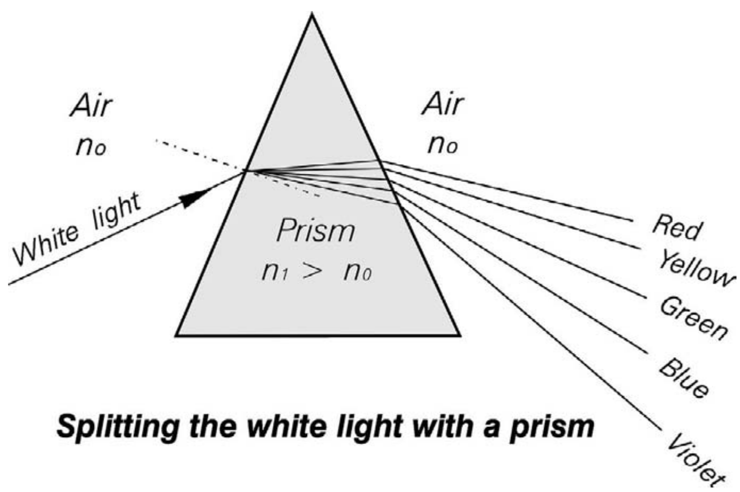
As an example of why this is necessary, let us examine a sun ray falling onto a prism.

We all know the rainbow effect produced on the other side of the prism. This happens because the "white" rays coming from the sun are composed of all the wavelengths (that is, colors) the human eye can see. Because they all enter the glass prism with the index of refraction $n_1 > n_0$, different wavelengths are changed at slightly different "rates" (proportional to their frequency), thus producing the rainbow at the other end of the prism. This is actually a **decomposition of the white light**. The color red has the longest wavelength (lowest frequency); therefore, it is refracted least. The color violet has the shortest wavelength (highest frequency); therefore, it is refracted the most.

A very similar effect is the fabulous rainbow after the rain, which is actually the refraction and reflection of sun rays through the raindrops.

No matter how impressive this effect looks, it is an unwanted effect in a lens design.

A convex lens can be approximated with many little prisms next to each other, forming a mosaic. It is, then, obvious that the image created by such a lens using daylight (which is actually most common) will be decomposed into the basic colors as is the case with the prism light decomposition.

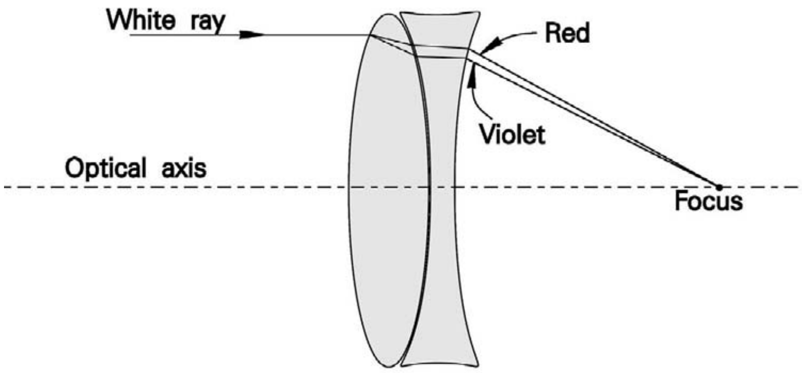


Splitting the white light with a prism

This means that when white rays fall onto a simple convex lens, **the focal point will vary for different colors.** This is an unwanted effect, called color distortion of a lens, or a ***chromatic aberration*.**

So, it should be clearly understood that chromatic aberration happens not so much because of the imperfection of the lens manufacture (although this is not excluded), but rather because of the physical process of decomposing white light into the basic wavelengths when the light passes through a single piece of lens.

Chromatic aberration **can** be minimized by **combining convex and concave** lenses together, where a white ray is first split by the convex lens into a "dispersed rainbow" but is then "put back together" by the concave lens **because of the opposite effect of the concave lens** (relative to the incident angle).



Chromatic aberration correction

When the two lenses (convex and concave) are chosen carefully (in respect to their thicknesses and focal points), the result is that all the colors come together in the focus and form a single focusing point. This is achieved with a proper selection of the convex-concave pairs, preserving the wanted combined focal length as in the single-piece lens. A special transparent glue is used to join the two lenses.

This is just a very simple example of why numerous optical elements are required to compose a lens of a certain focal length.

Lenses produce many other distortions, not just the chromatic aberration, but among others, also geometrical ("pincushion" and "barrel") and spherical. The name suggests the type of distortion it adds to the image. These can also be corrected by adding some more optical elements to the group.

When designing a lens, optical engineers have to balance between a lens with as many corrections as possible (in order to get a good quality picture), but also as few elements as possible (in order to be economical and technologically acceptable).

One can imagine how many combinations are possible when designing a lens with a particular focal length with half a dozen (or more) different optical elements. Earlier, optical engineers used to work together with mathematicians when designing a lens with a certain focal length, and size, and they used to do hundreds and hundreds of calculations and iterations manually. The physical size, the focal length, and the absolute and relative positions of every element are all variables. The only way to find such a combination of a known focal length was by painfully long iterations.

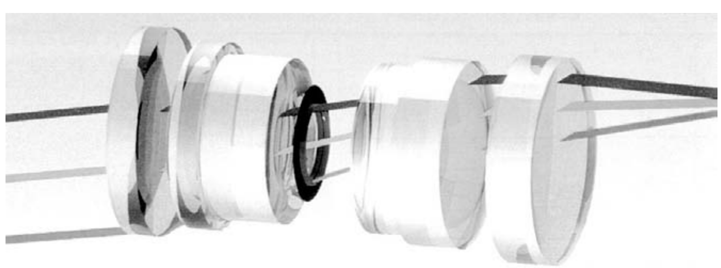


Photo courtesy of Edmund Scientific

Group of lenses with an iris

Obviously, the desired result was to get a good quality lens without going overboard with the number of optical elements. Since this was quite a challenging task, manufacturers used to register the particular lens design with their "recipe" of how many lenses, what focal length and at what positions they were placed. That is why in cinematography and photography we may still see the lenses of a certain manufacturer with names like Planar, Xenar. These names are actually patented designs of lenses for a particular lens size and focal length.



Typical markings on a CCTV lens

Today, in the computer era, there are many professional programs for computerized optical simulations. Within a few minutes optimum results are obtained, suggesting only as many optical elements as necessary, yet correcting all the visible distortions.

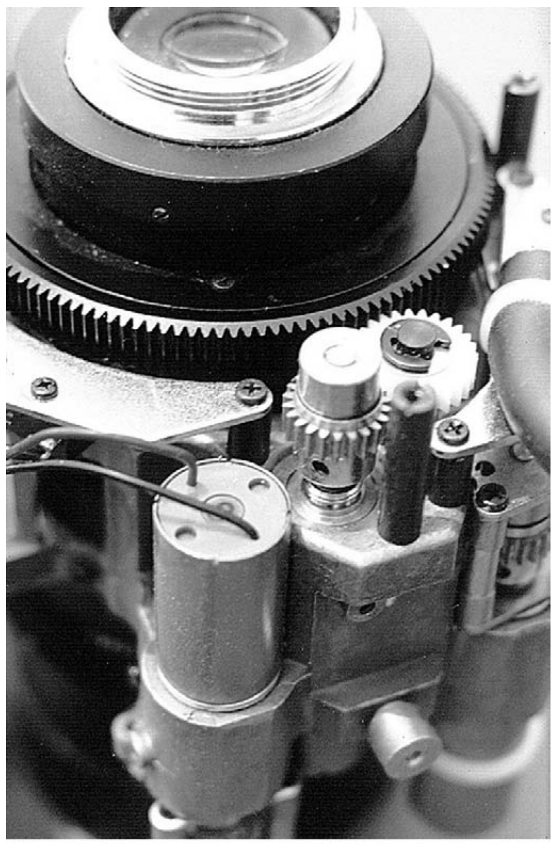
This is why lenses of a certain focal length are available with different costs and sizes, all giving the same viewing angle but different picture quality.

Lens quality depends on many factors, and one should not take it for granted. This is especially important with zoom lenses, as there are so many variables in their design. Zoom lenses are widely used in most of the bigger CCTV systems, so we should be very careful when choosing them.

There is no simple rule, so the best suggestion, again, is to do some testing and comparisons.

The factors that determine the lens quality can be summarized by the following points:

1. Lens design
   - Number of elements
   - Relative position
   - Aberration correction in the design stage
2. Lens elements manufacture
   - Glass type
   - Technology and type of glass manufacturing (heating, cooling, cleanness)
   - Precision of grinding and polishing (very important)
   - Antireflection coatings of the glass (micrometer layers for minimizing losses)
3. Lens mechanical composition
   - The lens's positional fixing and stability (shock, temperature)
   - The lens's moving mechanics (especially zooming, focusing, iris leaves)
   - Internal light reflections (matte black absorption)
   - Gears used for motorized lenses (plastic, metal, precision)
4. Electronics (refers to auto iris and motorized lenses)
   - Auto iris electronics quality (gain, stability, precision)
   - Electric consumption (auto iris – usually low, but some older models may require more than a camera can give since the camera powers the auto iris)
   - Zoom and focus control circuitry (voltages: 6, 9, or 12 volts, three- or four-wire control)



Zoom lens mechanics



Disassembled zoom lens

Geometrical construction of images

Images can be constructed by using simple optical and geometrical rules. As can be seen on the following drawing, at least two rays are used to create the image of an object.

There are three basic rules to follow:

- Objects taken at various distances touch the optical axis with one end.
- By definition, rays that pass through the center of the lens do not change direction, that is, in the center, a lens behaves like parallel glass and no refraction occurs.
- By definition, all rays parallel to the optical axis pass through the focus.

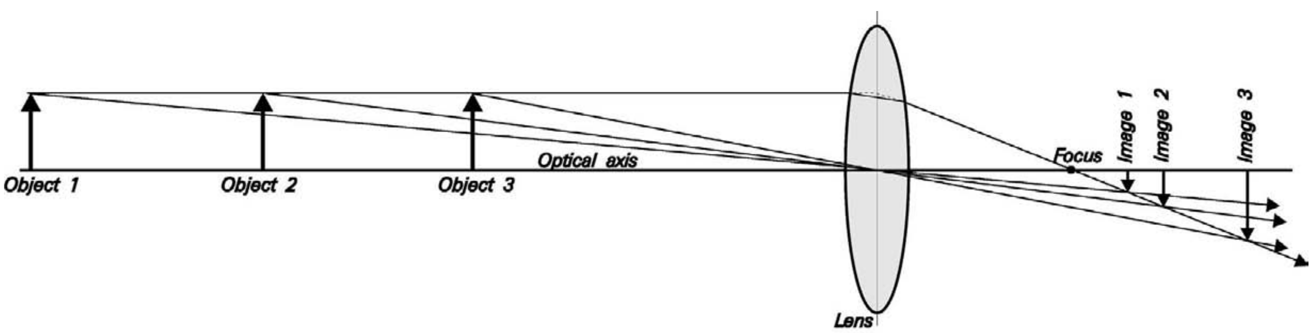


Image projection of different object distances

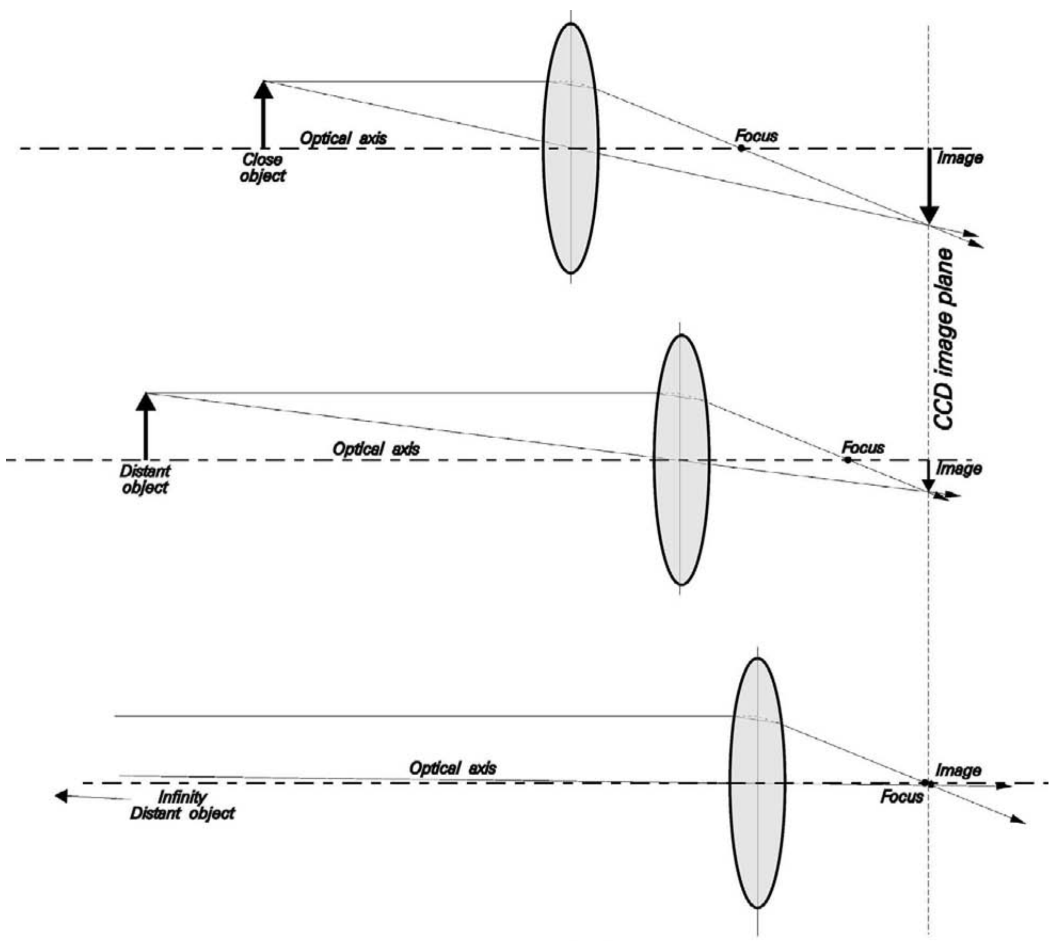
There is a very basic lens formula, worth mentioning, which we use when calculating the light falling onto a CCD chip:

$$1/D + 1/d = 1/f \qquad (30)$$

where D is the distance from the object to the lens, d is from the lens to the image, and f is the focal length of the lens. Note that d refers to a noninfinite distance object image and that is why it is bigger than f, whereas if the object is at an infinite distance, d would be equal to f.

Please note the position of images for various distance objects. **Lens focusing is achieved by changing the distance between the lens and the image plane** (which is where the CCD chip is located). So, ***only* when a lens is focused at an infinitely far object does the image projection coincide, with the focus plane**. In all other cases the distance between the lens and the image is bigger than the focal length of the lens.

It should also be noted that in practice, a lens is composed (as discussed earlier) of many optical elements. Therefore, they are represented by an equivalent single-element lens located at the principal point. The following drawing explains this.



The concepts of focusing

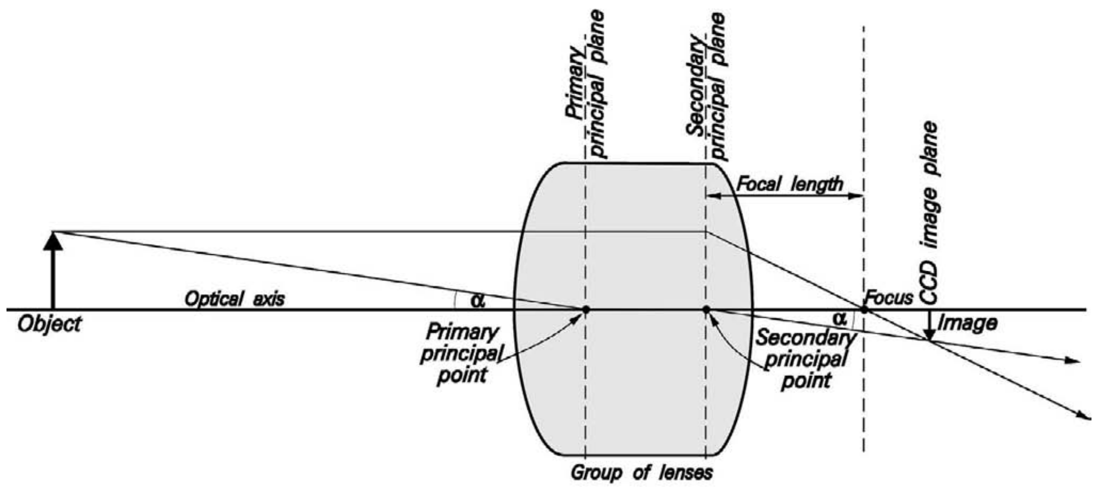
A lens composed of many optical elements (single thin lens) has **two principal points** called **primary** and **secondary principal points**. **For a thin lens, these points coincide and they are located at the center of the lens.**

The planes that pass through these principal points and are perpendicular to the optical axis are called ***principal planes***.

The principal planes have the following properties:

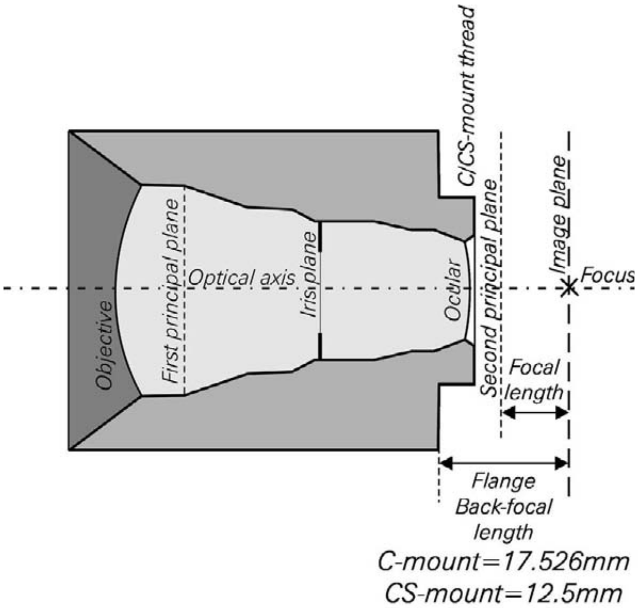
- A ray incident to the primary principal plane (and parallel to the optical axis) will leave the secondary principal plane at the same height, traveling toward the focal point (focus).
- An incident ray directed toward the primary principal point will leave the secondary principal point at the same angle.
- The focal length of such a lens is measured from the secondary principal plane to the focus.

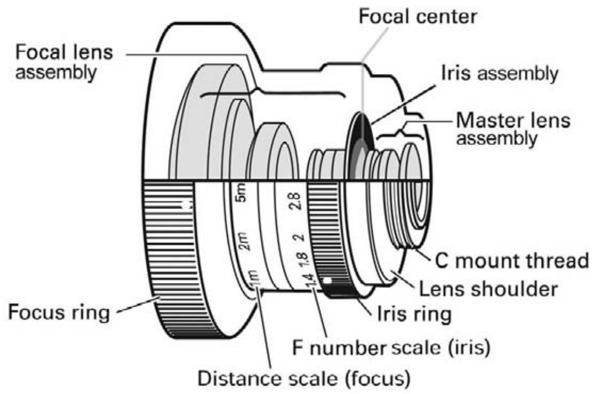
Using the above properties, we can construct a geometrical image in the same manner as was shown with the single optical element.



Principal points and planes

The secondary principal point may fall outside the group of lenses. This is the case with very short focal length lenses. The shorter the focal length is, the more optical elements have to be added for correcting various distortions, making the lens more expensive. With the CCD chip reduction (2/3" down to 1/2", then to 1/3", and now to 1/4"), shorter focal length lenses have to be manufactured in order to preserve the same wide angle as the preceding chip sizes. This, in turn, has forced the industry to reduce the C-mount 17.5-mm back-flange distance in order for the optics to get simpler, smaller, and cheaper. The new format of back-flange distance is 12.5 mm, and since it is smaller, it is referred to as the CS-mount standard.





Drawing courtesy of Elbex

Cross section of manual iris lens

Aspherical lenses

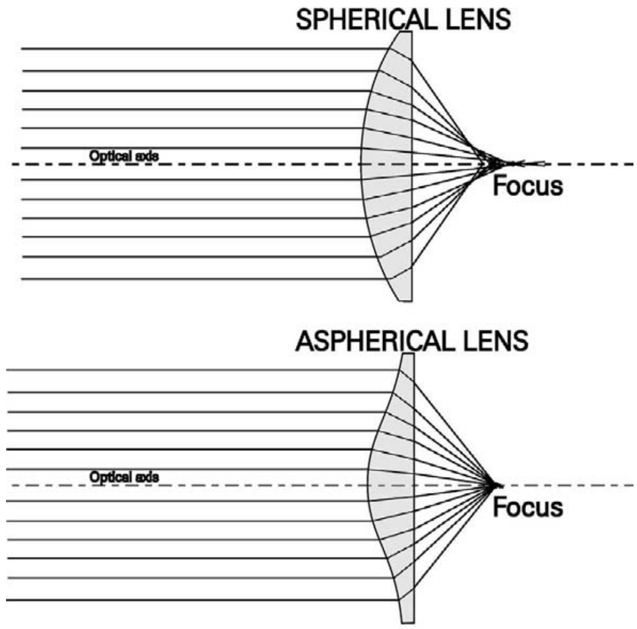
As mentioned earlier, spherical aberration is a common distortion that appears in the majority of lenses of a spherical type. Spherical-type lenses are the most common since they are produced by grinding and polishing in the easiest mechanical way, following the spherical laws. This refers to a circular machine polishing with the result being a lens of a spherical appearance. It can be shown that apart from the chromatic aberrations present in a single-lens element (the “color decomposition” of white light), aberration also occurs because of the spherical profile of the lens. The focus is not a very precise single point.

Theoretically, using the physical laws of refraction, we can show (but we will not go into the details) that a bell-shaped lens, which does not follow the spherical law, is the ideal shape for obtaining a single focusing point without spherical distortions. The cross-section profile of such a lens is a curve that deviates slightly from a circular shape, appearing more bell shaped. This type of lens is called an ***aspherical lens***.

The drawing on the next page shows this in an exaggerated form in order to help the reader understand it.

Understandably, such a shape is hard to produce by regular polishing techniques, but if properly manufactured, it offers quite a few advantages over the conventional spherical lenses, including **higher iris openings** (which is reflected in a lower F-stop), **wider angles of view, shorter minimum object distances,** and **fewer optical elements** because there are fewer aberrations to correct (thus resulting in lighter and smaller lens designs).

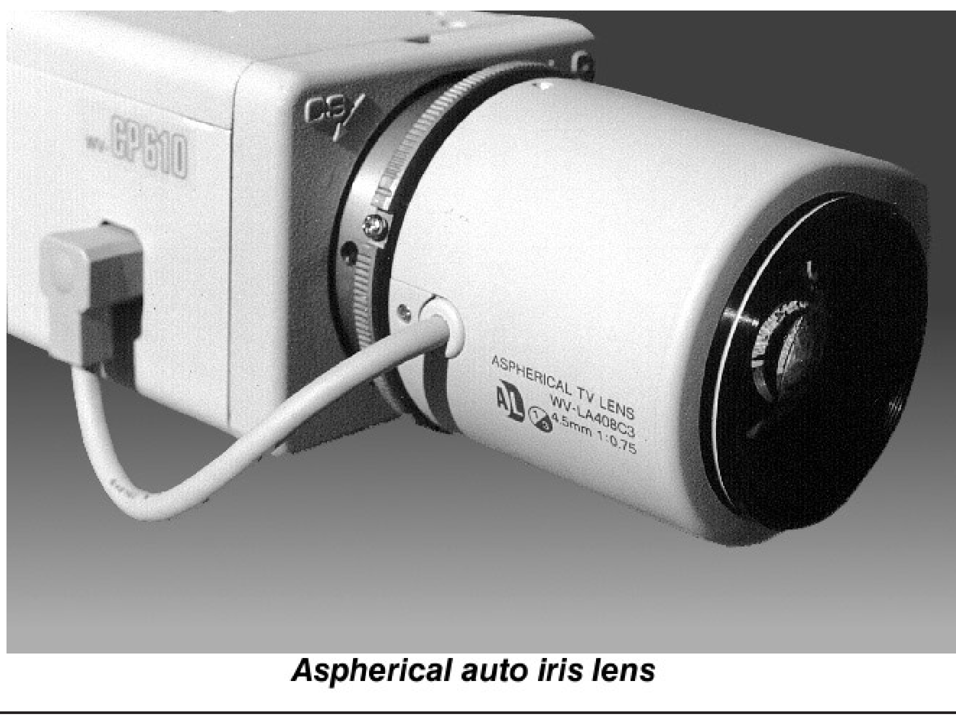
This technology is more expensive due to the aforementioned complex polishing techniques.



Spherical and aspherical lenses

Some optical companies have started producing **molded** aspherical lenses, avoiding the critical process of grinding. This process does not offer the same glass quality as the regular one, but it does offer a solution for more economical production of aspherical lenses.

The quality of such lenses is yet to be proven, but they do exist and are available in the CCTV market as well.



Aspherical auto iris lens

CTF and MTF

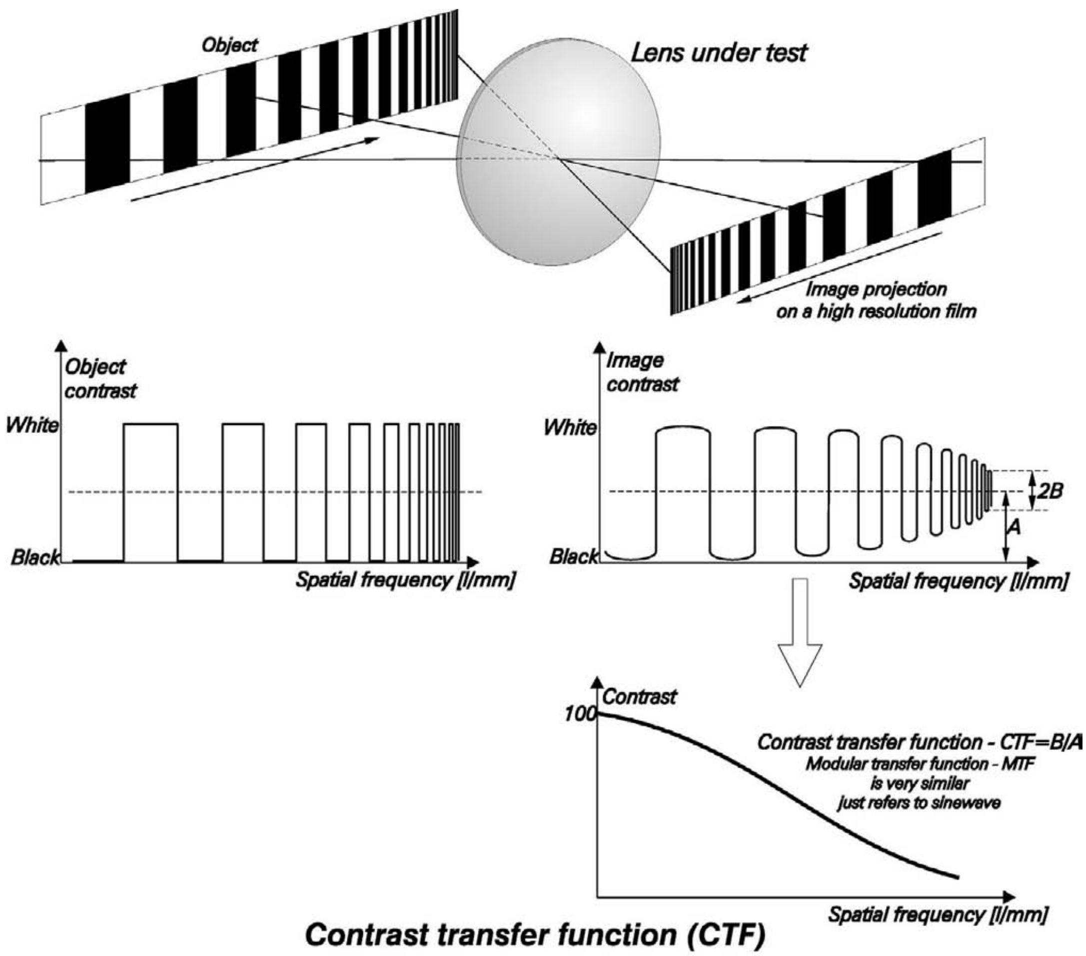
What we want from a lens are sharp and clear images, free of distortions.

As already mentioned, lenses have limited resolving power, and this is especially important to have in mind when using them in high-resolution systems.

Resolution refers to the lens's ability to reproduce fine details. In order to measure this ability, a chart that consists of black and white stripes with various density (spatial periods) is used. **This is usually expressed in lines per millimeter** (lines/mm). When counting how many lines/mm a lens can resolve, we count both black and white lines.

A characteristic that shows the "response" of a lens to various densities of lines/mm is called a ***Contrast Transfer Function*** (CTF).

Theoretically, it is better to know the lens characteristics for a continuous variation of black to white (in



Contrast transfer function (CTF)
and
Modulation transfer function (MTF)

the form of a sine wave), and not just for stripes that abruptly change from black to white. This would be especially suitable for TV lenses since the optical signal is converted into an electrical signal with which sine waves are easier to represent and evaluate. This characteristic is known as a ***Modulation Transfer Function*** (MTF).

In practice, however, it is much easier to produce a test chart with just black/white stripes rather than the sine wave variation between black and white. CTF is not the same as MTF, but it is much easier to measure and is **precise enough to describe the lens's global characteristics.**

The easiest analogy of MTF to understand would be the spectral response of an audio system. In an audio system we usually describe the output level (voltage or sound pressure) versus the audio frequency. In optics it is similar, where MTF is expressed in contrast values (from 0 to 100%) versus spatial frequency (expressed in lines/mm), as can be seen on the previous page.

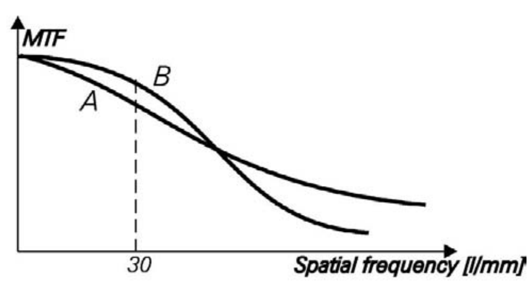
Different lenses have different MTF characteristics, depending on the quality of the glass, optical design, and application. For example, a photographic lens will have a better MTF than a CCTV lens. The reason for this is simple: the photographic film structure can register over 120 lines/mm and manufacturers need to produce better lenses in order to minimize picture deterioration when film is blown up to a poster size.

CCD chips have a lower resolution than the film crystal structure. Technically, **there is no need** to go to the "expense" of producing a lens with much higher resolution than a CCD chip. With the miniaturization of CCD chips, however, we are actually coming closer to the film resolution limits, so lenses need to feature better characteristics.

An average 1/2" B/W CCD chip, for example, has approximately 500 pixels (picture elements) in the horizontal direction. When we take into account the physical width of the 1/2" CCD chip (6.4 mm), we can conclude that the maximum number of vertical lines (black and white pairs) we can have is (500:6.4):2 = 39 lines/mm. This resolution is easily achieved with most TV lenses, since the optical technology can produce over 50 lines/mm. But for a 1/3" B/W CCD chip, with the same density of 500 pixels horizontally, we are actually talking about (500:4.4):2 = 57 lines/mm. This means that a 1/3" CCD camera **demands more** from the lens resolution than a 1/2" one.

Different lenses have different MTF characteristics, and sometimes it may be necessary to decide which one to use on the basis of these characteristics.

The diagram presented here shows such an example. We can evaluate this in the following way. Lens *A* has its MTF extending into the high spatial frequency range, which means it can resolve finer details than lens *B*. Lens *B,* however, has better response in the lower frequencies. If we need a lens for a high-resolution output, like film, for example, lens *A* will be a better choice, but for CCTV purposes, where a CCD chip cannot see more than 50 lines/mm, we are better off with lens *B* since we will have better contrast with it.



MTF curves of two different lenses

F and T numbers

In addition to the MTF and CTF characteristics of a lens, the ***F-number*** (more commonly, the ***F-stop***) is also a very important parameter.

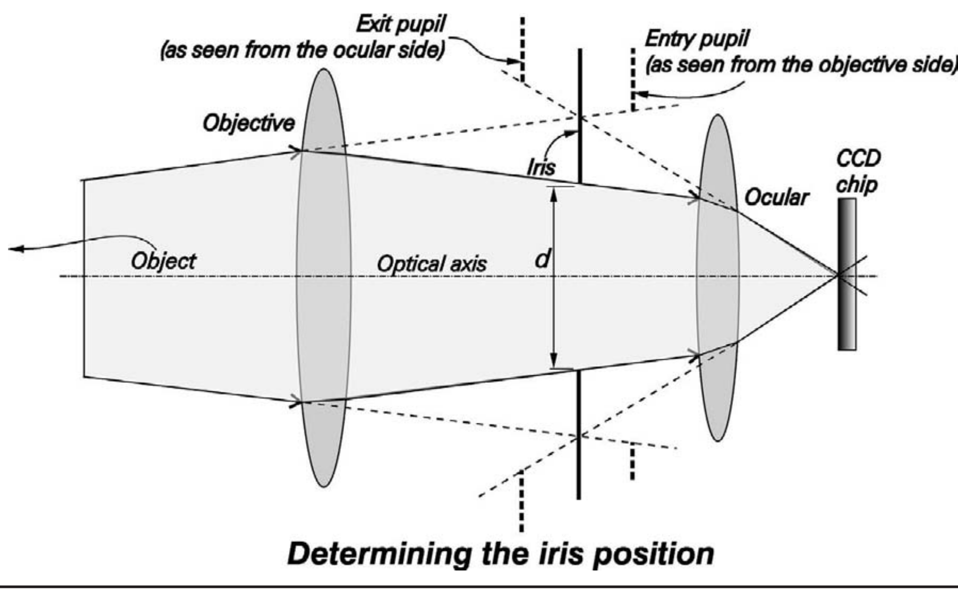
The F-number indicates the brightness of an image formed by a lens. This is usually written (engraved) on the lens itself as F-1.4, for example, or sometimes in another form, such as 1:1.4. The F-number depends on the **focal length** of the lens and the **effective diameter** of the area through which the light rays pass. This area can be controlled by a mechanical leaves assembly, which we usually refer to as the *iris*.

It is important to note that the **effective diameter** of a lens is not the actual lens diameter, but rather the **diameter of the image of the iris as seen from in front of the lens.** The first lens diameter is usually called the ***entrance pupil.*** There is also an ***exit pupil***, as shown on the diagram below. The actual iris diaphragm is positioned between these two pupils, which also happens to be between the two principal points.

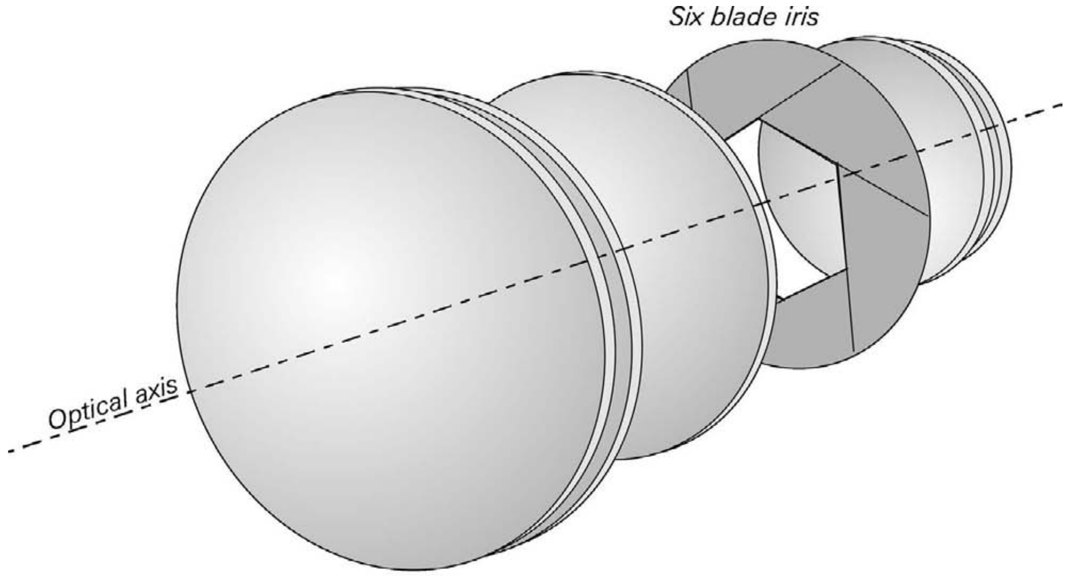
The lower the F-number the bigger the iris opening is, and that means more light is transmitted through the lens. The lowest number for a particular lens is the number engraved (or written) on the lens itself, representing the **light-gathering ability** of that lens.

Often, the lower F-stop lenses are called ***faster lenses***. The reason for this is that, in the early days of photography, by increasing the amount of light (lower F-stop), the film exposure time needed to be shortened, thus allowing pictures with fast action to be taken without losing any sharpness because of camera movement.

If a 16 mm lens has a minimum F-stop of 1.4, for example, it is usually written as 16 mm/1.4, or sometimes as 16 mm 1:1.4. The maximum effective iris opening is equivalent to a circle with a diameter of 16/1.4 = 11.43 mm – equivalent because the iris leaves would usually make a triangle, a square, a pentagon, or a hexagon opening.



Determining the iris position



The iris position and size depend on the lens type and design.

In order to understand the consecutiveness of the F-numbers, we will have to do some simple calculations.

Starting with the above example of a 16 mm/1.4 lens, let us find the area when the iris is fully open (that is, at F-1.4):

$$A_{1.4} = (d/2)^2 \cdot \pi = (11.43/2)^2 \cdot \pi = 32.66 \cdot 3.14 = 102.5 \text{ mm}^2 \quad (31)$$

Let us halve this area – that is, take 51.25 mm^2 as a new area, and let us calculate what the iris opening is:

$$A_x = (x/2)^2 \cdot \pi \Rightarrow x = 2 \cdot \sqrt{(A_x / \pi)} = 8 \text{ mm} \quad (32)$$

where √ is a square root. Now, the F-stop with an 8 mm iris opening would be 16/8 = 2, that is, F-2.

Here we have F-2 representing an area that is exactly half of the F-1.4. If we proceed with the same logic, we will get the following familiar numbers:

2.8; 4; 5.6; 8; 11; 16; 22; 32; etc.

All of these numbers are common to all types of lenses, and what they mean is that **every next higher F-number transmits half the amount of light of the previous F-number**.

Now it should be much clearer why a 16 mm/1.0 lens makes the same camera look more sensitive than, for example, when a 16 mm/1.4 lens is used.

For zoom lenses, the F-numbers quoted refer to the iris opening at the shortest focal length of the zoom lens. This is obviously the best "light-gathering number" of every lens. The F-number of the same zoom lens at a longer focal length setting (tele) is always smaller than at the shorter end. But it

is wrong to assume a linear function of the F-stop versus the focal length. Namely, if an 8–80 mm/1.4 lens is in question, it makes an 8/1.4 = 5.7 mm effective iris opening, while with the same iris at 80 mm we should have an F-stop of 80/5.7 = 14. This simply is not the case because it depends on the zoom lens construction. The iris plane may vary in relation to the moving parts of the zooming components, obeying a **nonlinear law**. In most cases we have much better values for the F-stop at the higher focal length than indicated, but they are still worse than at the lower focal length.



Vari-focal lenses have become very popular.

It is fair to say that every piece of glass, no matter how good it is, introduces some light loss. These losses might be a very small percentage of the total light energy, but they should be considered if accurate lens characteristics need to be taken into account. An indication of lens's level of light transmission is shown by the ***transmittance factor***, which is always less than 100%. This is why many professionals prefer to use T-numbers instead of F-numbers.

The definition of a T-number takes the F-stop and the lens transmittance into account:

$$\text{T-number} = 10 \cdot \text{F-number}/\sqrt{(\text{Transmittance})} \qquad (33)$$

where the symbol √ means square root. Since the transmittance of a lens is, as mentioned, always less than 100% (usually 95 to 99%), it is obvious that the T-number will be a bit higher than the F-number. For example, if a 16 mm/1.4 lens has a transmittance of 96%, the T-number will be equal to 1.43.

Depth of field

When a lens is focused on an object, theoretically, the whole plane passing through the object and perpendicular to the optical axis should be in focus.

Practically, objects slightly in front of and behind the object in focus will also appear sharp. This "extra" depth of sharpness is called ***depth of field***.

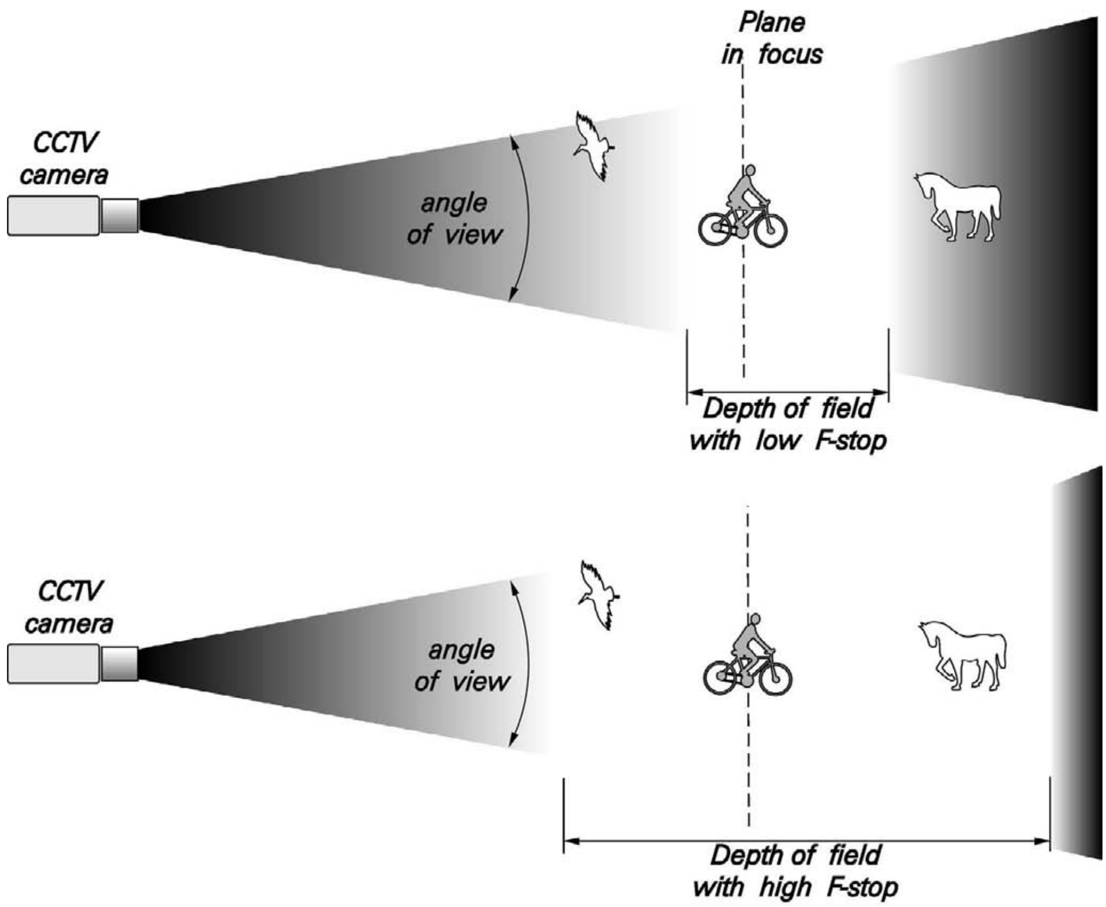
A wide depth of field might be an undesired feature, as it is, for example, when we want an object we are photographing to be isolated from the foreground and the background. This is very characteristic when taking portrait shots with a telephoto lens, where the depth of field is very narrow.

In CCTV, however, we often want the opposite effect. We want to have as many objects in focus as possible, no matter where the real focusing plane is.

The depth of field depends on the focal length of the lens, the F-stop, and the format size of the lens (2/3", 1/2", etc.). A general rule is **the shorter the focal length, the wider the depth of field; the higher the F-stop, the wider the depth of field, and the smaller the lens format, the wider the depth of field.**

The depth of field effect is explained by the so-called ***permissible circles of confusion***. The permissible circle of confusion is a projected circle of the depth of field area. If the smallest picture element (pixel) of the CCD chip is equal to or bigger than the permissible circle of confusion, then it is obvious that we cannot see details smaller than that circle. In other words, all objects and their details that appear within the circle will look equally sharp, since that is the actual size of the pixels. From this it is clear that the size of the permissible circles of confusion for a CCTV camera is determined by the pixel size of the CCD chip – in other words, the chip resolution.

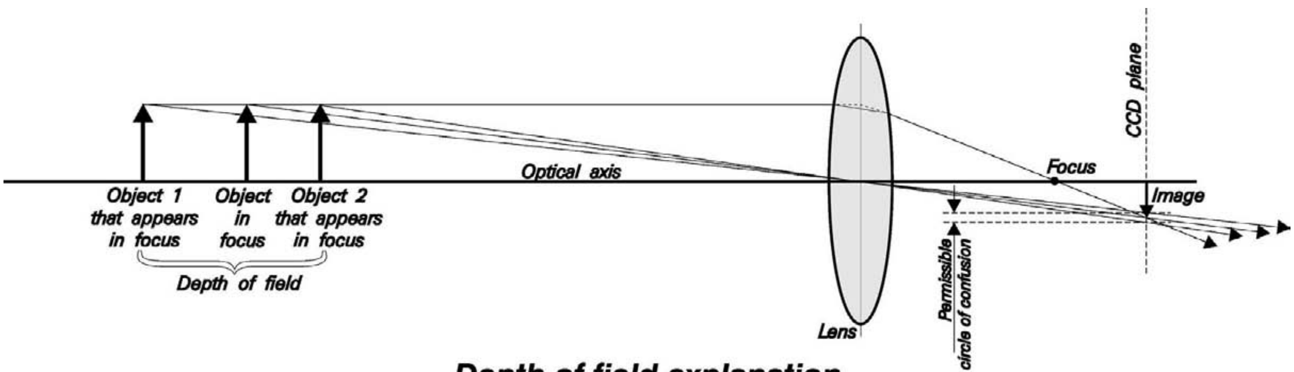
It may now be understood why some short focal length lenses in CCTV, such as 2.6 or 3.5 mm, **do not have a focusing ring** at all but only an iris adjustment. This is because even with the lowest F-stop for that lens (be it 1.4 or 1.8) the depth of field is so wide that it actually shows sharp images from a couple of centimeters in front of the lens up to infinity. There is literally no need for focusing.



Depth of field with various F-stops

As shall be explained later in the book, the depth of field is an effect of which we should be very aware, especially when adjusting the so-called back-focus. If the back-focus is not adjusted properly, and a camera is installed at daylight (that is when the auto iris of the lens closes the iris as much as possible, due to excessive light), the depth of field will produce sharpness even in areas that are not really in focus.

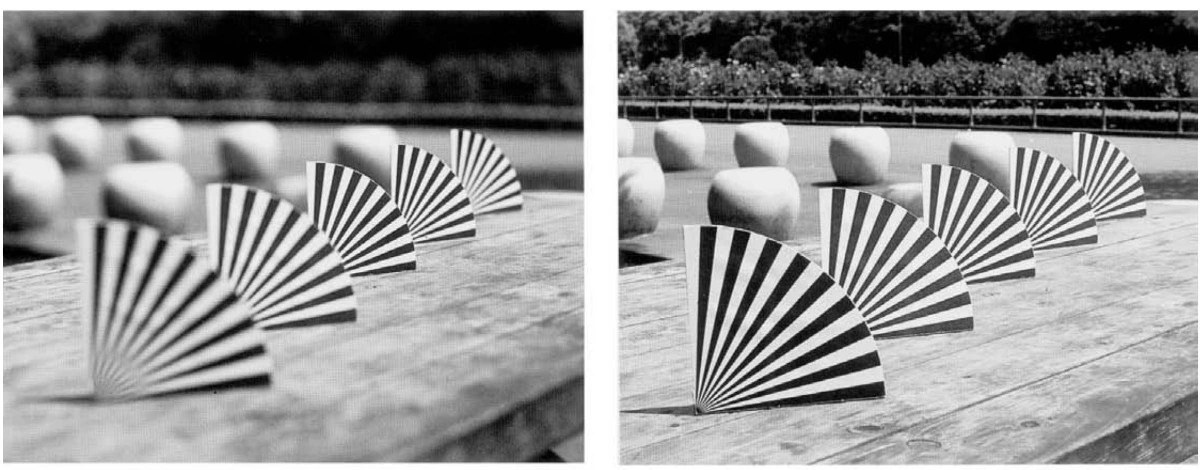
Practical experience shows that depth of field applied in this way (when the back-focus is not done correctly) is the biggest source of frustration for a 24-hour operating system. The reason is obvious: at night, when the iris opens due to a low light level (providing the AI functions properly), the depth of field narrows down and shows the images out of focus even if they were in focus during the day. When an operator complains to the installer or service people, not knowing the cause of such a problem, he or she usually gets the service to visit during the daytime. Obviously, the problem will not be there then, thanks to a wide depth of field that reappears "inexplicably" at nighttime.



Depth of field explanation

The moral of the above is that the back-focus adjustment (discussed later in the book) should be done when the iris is fully opened. The easiest way to have the iris opened is when low light levels reach it, either at the end of the day (or at night), or by artificially reducing the daylight with external neutral density filters (usually placed in front of the lens objective). All this is in order to reduce the depth of field and consequently make back-focus adjustment easier and more accurate.

Quite often, when B/W cameras with infrared lights are used, another effect is present. Because of the extremely long wavelength of the infrared light (compared to normal light), and the lesser angle of refraction, we get the focused image plane slightly behind the CCD chip. Refer to the heading Lenses as Optical Elements for further explanation of this phenomenon. If an image is sharp at day, then at nighttime objects of the same distance will be out of focus. This might be a quite noticeable and



Photos courtesy of Canon

Photos with a low F-stop and a high F-stop (lens focused on the central object)

unwanted effect. In order to minimize it, a lens should be designed with a special compensation for infrared viewing (some manufacturers have special glass lenses for this purpose). However, a more practical and common solution would be to have the camera back-focused at night with an infrared light on, in which case the depth of field is minimal but the objects are in focus. At day, the depth of field will increase the sharpness to a wider area, compensating for the difference between the infrared and the normal light focus.

Neutral density (ND) filters

Earlier, when we discussed F-stops, we also mentioned some F-numbers – 1.4, 2, 2.8, 4, 5.6, 8, 11, 16, 22, 32, and so on. This list continues – 44, 64, 88, 128, and so on. The higher the F-number, the smaller the iris opening is.

For photographic or movie film, F-32 is considered quite a high number. The film emulsion is so sensitive that even on the sunniest days, this F-stop, combined with the available shutter speed, is enough to compensate for the excessive light.

Film sensitivity is measured in ISO units, and the most common film we use for everyday purposes has a sensitivity of 100 ISO units.

CCD chips are much more sensitive than a 100 ISO film, especially the B/W chips. Starting from known light levels, the F-stop, and shutter speed of a photographic camera, the typical electronic exposure time of a TV camera (1/50 s for CCIR/PAL), and the iris setting, we can calculate that a B/W CCD chip's sensitivity is close to the 100,000 ISO units mark. This is quite a high sensitivity.

Translated into everyday language, this means that CCD chips are so sensitive that the low light level situation is not really a problem (although you would have a lot of customers asking you, "How sensitive is your camera?"), but rather the strong light.

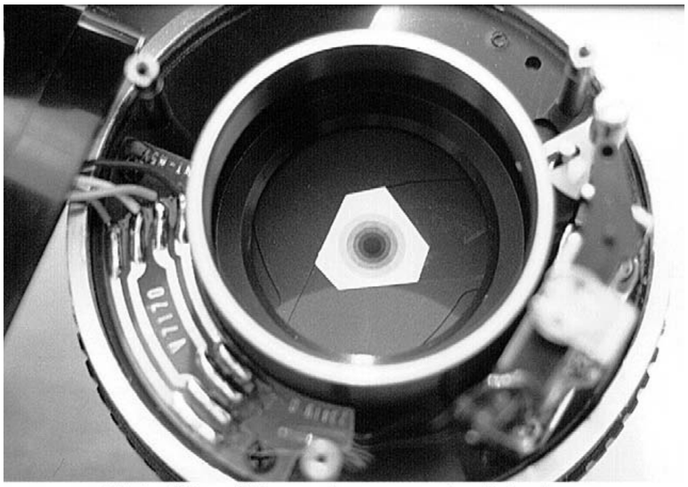
Since television cameras use one exposure speed only, 1/50 s in CCIR and SECAM, and 1/60 in NTSC (not considering the CCD-iris cameras), we can only manipulate the F-stop to reduce the amount of light.

An average B/W CCD chip requires 0.1 lx at the chip to produce a full video signal. A bright sunny day at the beach, or on the snow, produces more than 100,000 lx at the object. To reduce this to 0.1 lx, very high F-stops, in the order of up to F-1200, need to be used. Using the basic definition for F-stop, for an average 16 mm/1.4 lens, we will get F-1200 to be an effective iris opening of 16/1200 = 0.013 mm.

Mechanically, this is impossible to produce because of the very small size and precision required, but also because with such a small iris we would introduce new problems such as edge diffraction of light (known as the Fresnel effect), which will affect the picture quality.

The solution was found in the use of ***internal neutral density* (ND) *filters***. These are very thin films of circular, neutral color coatings, positioned in the middle of the lens, close to the iris plane. The filters get less transparent toward the middle of the concentric circles. The F-stop is thus achieved by

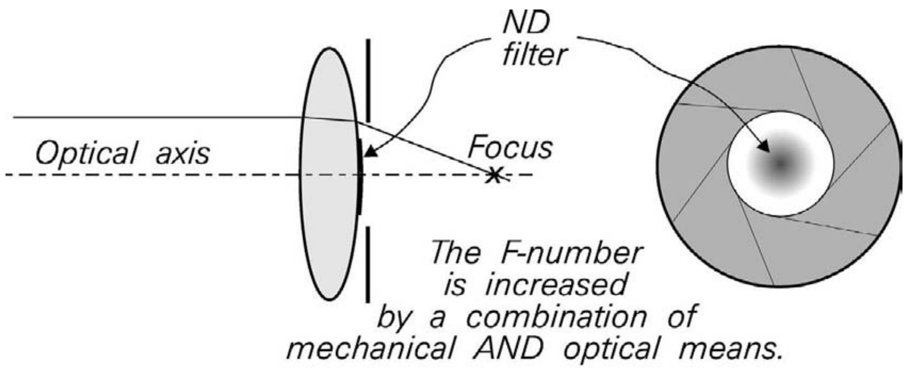
a combination of the mechanical iris (leaves) and the optical ND filter (optical attenuation). This is a very simple and efficient way of battling strong light. The filters are called neutral because they attenuate all wavelengths (colors) evenly, therefore not changing the color composition of the image.



ND film filters in an auto iris lens

The optical precision of such thin films is very important in order to preserve the lens's MTF characteristics as the F-stop increases. Theoretically, the resolving power of any lens is best in the middle of the mechanical iris setting, and it reduces as the F-stop goes lower or higher (this is different from the depth of field effect), but the ND filters may reduce it even further. Whether or not this will be obvious depends on the quality of the lens in general.

Apart from the internal ND filters, there are also ***external ND filters***, which are not so sophisticated. These are just precise semitransparent pieces of glass, or optical filters if you like, that attenuate the light × number of times. This may be 10, 100, or 1000 times. Two or three of these can be combined, so, for example, 10 with 1000 times will result in an ND filter with 10,000 times attenuation.



On-lens ND filters

Sometimes, and probably more correctly, the attenuation of the external ND filters is expressed in F-stops. Knowing that every next F-stop will divide the light gathering ability by 2 (50% of the previous number), we can establish the following logic: 100 times ND filter is divided by 100, which is halfway between 2^6 and 2^7 ($2^6 = 64$, $2^7 = 128$). This means 100 times attenuation is approximately 6.5 F-stops. One thousand times attenuation is close to 2^{10}, which means approximately 10 F-stops.

These types of ND filters are very handy, as already explained, for minimizing the depth of field for the purposes of back-focus adjustments or AI level adjustments during the daytime.

Manual, auto, and motorized iris lenses

Manual iris (MI) lenses adjust the iris manually (that is, by hand). These lenses are very common in areas with constant light, such as shopping centers, underground car parks, and libraries. Basically, these are areas where natural light does not interfere noticeably with the ambient, and therefore we have almost constant artificial light. Eventual small variations are compensated by the camera's automatic gain control (AGC).

With the introduction of the CCD-iris cameras, however, fixed iris lenses are used in light-varying areas as well, since the CCD electronic iris adjusts the exposure time, compensating for the light variations.



Manual iris fixed focal length lenses

Two major factors decide at what F-stop (iris) a manual iris lens should be set for optimum performance:

- Light intensity
- Depth of field

These factors contradict each other, and that is why MI settings are always a compromise. When using it in very low light level situations, or when using not so sensitive cameras, the general tendency is to open the iris (low F-number) as much as possible. Obviously, in such cases the depth of field, as well as the MTF, as explained previously, will be minimal. We should not forget that apart from the depth, the lens resolution at the lowest F-stop is usually the poorest. A compromise is often the best solution (if the camera's minimum illumination characteristic allows for it), and the lens is set to one or two



Photo courtesy of Cosmicar (Asahi Precision Co.Ltd.)

Auto iris fixed focal length lenses

F-stops higher than the lowest (e.g., F-2, F-2.8).

Auto iris (AI) lenses have electronic circuitry that processes the video signal coming out of the camera and decides, on the basis of the video signal level, whether the iris should open or close.

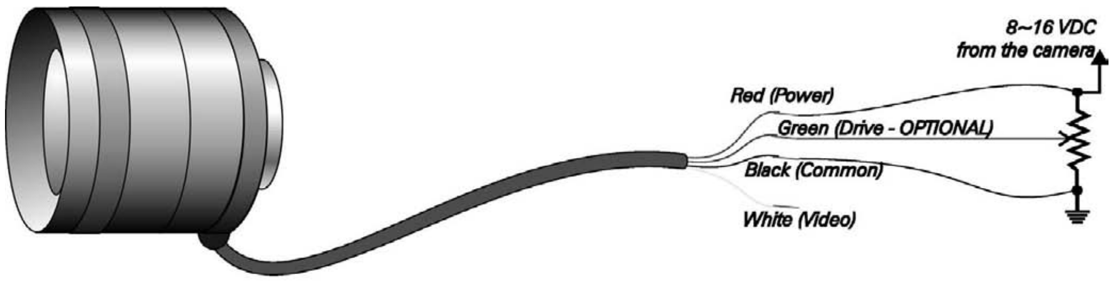
Auto iris works as automatic electronic-optical feedback. If the video signal is low, the electronics tells the iris to open, and if it is too high, it tells it to close.

In order to do this, the AI lens **takes power from the camera** (usually 9 V DC), **as well as the video signal** and references the electronics of the lens and the camera with a third common wire (called zero, negative, or common). Quite often, you will find lenses with shielding as well. This is to protect the video signal wire from strong external electromagnetic interference. Usually, this wire does not have to be connected to the camera body because the connection is already made with the lens's metal ring when fitted on the camera. By keeping the AI cable as short as possible, the amount of unwanted interference induced in the video signal is minimal. This goes hand in hand with the ever decreasing camera size. Be aware, however, of plastic C/CS-mount adaptors that will not common the lens case with the camera's body.

Following are some color codes for the AI wires that are widely accepted in the industry:

- Black is usually used for common,
- Red for power (derived from the camera), and
- White for video.

Some manufacturers, in order to lower manufacturing costs, have started using two-wire AI cables (red-power and white-video) with a shielding used as the common wire.



A typical video-driven auto iris lens wiring

Often, lenses with four-wire cables can be found, where the fourth wire is usually green. In most cases this is an unused wire, but in some lenses it offers remote control of the iris, usually known as ***motorized iris*** (MRI) control. When such control is wanted, the iris opens and closes as instructed by the voltage from a site driver (controlled by an operator), much in the same way as zoom and focus are controlled.

The latter type of lens is the preferred one in systems with CCD-iris cameras. The reason for this is that CCD-iris and auto iris do not work well together. If the two of them are enabled, the electronic iris usually works faster, and by the time the mechanical auto iris responds to the light fluctuations, the electronic iris has already reduced the shutter exposure, forcing the auto iris to open more. The end result is a widely opened iris and a very short electronic exposure. This gives a 1 V_{pp} output signal as is expected, but the **depth of field is minimal and vertical smearing is more noticeable** because of the very short exposure of the CCD chip.

Because of this, when auto iris lenses are used, it is suggested that the CCD-iris be switched off. The electronic iris is, however, quicker and more reliable since there are no moving parts (only electronics), although it **does not control the depth of field.**

So, to gain the benefits of both, motorized iris lenses are now recommended with CCD-iris cameras. This can obviously be done only if a site driver with an iris control is used. In such systems, operators can adjust the iris according to the light-level situation and required depth of field, but only when drastic light changes occur.

The current consumption of the AI circuitry is usually below 30 mA, and it does not represent any noticeable load on the camera power supply. Be aware, however, as mentioned earlier, that older lenses (especially bigger zoom lenses) may demand more current drive, in which case (if a camera output current is not sufficient), a separate 9 V DC power supply has to be used for the auto iris electronics inside the lens.

Video- and DC-driven auto iris lenses

The division of lenses gets a bit more confusing in respect to the processing circuitry when auto iris lenses are in question. Namely, apart from the “normal” AI lenses we have in the majority of cases, where the electronics are built inside the lens itself and which we call *video-driven AI* lenses (since they require a video signal from the camera), we can also find so-called *DC-driven AI* lenses. These

lenses are similar to the video-driven ones, with the exception that **the processing electronics are not inside the lens but rather inside the camera.** The lens, in that case, has only the motor and the iris mechanism. Clearly, when DC-driven lenses are used, the camera has to be designed to have such an output. Instead of having power, video, and common wires, we will have power, DC level, and common connection. Often, these types of lenses are called Galvanometric auto iris lenses.

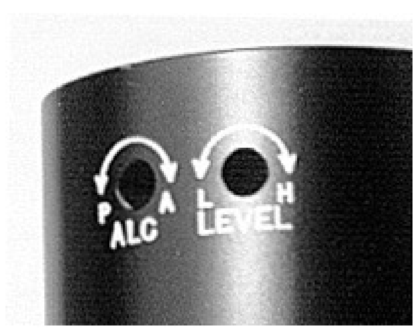
A DC-driven lens cannot be used on a camera that does not have that type of connector, and vice versa. If a camera has a DC auto iris connector, you will usually find level and ALC adjustments (explained in the following paragraphs) on the camera itself, instead of their being on the lens.

AI lenses, both fixed and zoom, have two potentiometers for adjusting the response and type of operation: **level** and **ALC** (automatic light compensation). This also applies to DC-driven lenses, only in that case, as mentioned above, the settings are on the camera itself.

Level adjusts the iris opening on the basis of the average level of the signal. The level is also known as sensitivity adjustment because of its appearance on the monitor screen as brightness variation of the object. When the level potentiometer is adjusted, iris operation should be checked both daily and nightly. If the working point is shifted too high, the picture may look okay at day but very dark at night. The opposite is also true: if the working point is shifted too low, it may be acceptable at night but too bright at daylight. To make sure that this does not happen, the best adjustment is achieved in the late afternoon with a little help from a torch. First, make sure the picture is as good at low light as it can be (that is, iris fully opened). Then, shine the torch at the lens and see if the iris closes sufficiently to see the torch filament only.

If tests cannot be conducted in the late afternoon, the alternative is to use some external ND filters. These filters can be selected to attenuate the daylight to the level equivalent to a low light level situation, which is usually a couple of luxes. Then, instead of using a torch, all it requires is to remove the ND filters and see whether and how the iris reacts.

ALC, as we have noted, stands for automatic light compensation. **The ALC is a photometric adjustment of the iris, and it should be thought of as "automatic backlight compensation."** The ALC part of the auto iris circuit decides on which portion of the video signal level the auto iris should react. ALC adjusts the video reference point for the iris operation depending on the picture contrast. In most cases, when the signal is "rich" with details from the darkest to the brightest (0 to 0.7 V), the reference level is in the middle. If very bright spots appear in the picture, they will participate in the calculation of the reference point and will force the auto iris to close to produce a video signal with "full dynamic" range. The visual appearance then will be a high-contrast picture. So, very bright objects (e.g., sun reflections, bright lights, windows and similar) will force the iris to close, making the dark objects even darker, sometimes too dark to distinguish any details. In such situations we may change the ALC setting from the factory default to the extreme position to make the iris disregard the bright areas and open more than usual. This allows for the objects in shadow to be more distinguishable.



ALC and level pots



A disassembled fixed auto iris lens

This adjustment is equivalent to the backlight compensation found in many camcorders. The backlight compensation is used, as the name suggests, to fight against the backlight. The idea is to tell the lens electronics to disregard the very bright areas of the image and open the iris more in order to see details of the darker objects in the foreground.

This is very useful when positioning the camera in hallways, for example, looking through glass doors and against a bright background. If a person walks in the hallway, he or she will be a silhouette. When the ALC is adjusted, the iris can be forced to open by one or two F-stops more, thus brightening the face of the person. Similarly, the ALC can be adjusted to do the opposite job, that is, close the iris more than it should in order to see details of the very bright background, as through the hallway door.

The ALC setting has two ends marked as Peak and Average. The first example above would correspond to Peak setting, and the second to the Average setting. Factory defaults are usually in the middle of these two positions. Please note that, in order to see the effects of the ALC adjustments, a very high-contrast scene is needed.

Auto iris lens electronics

As the optics quality of a lens cannot be taken for granted, neither should the electronics of an auto iris lens. Different circuit designs offer different quality and precision of operation. This, combined with the mechanical construction of the iris shutter, determines whether a lens is good, average, or bad. The responsiveness of the iris to abrupt light changes is not instant and ranges anywhere from half a second to two seconds. This needs to be taken into account when adjusting level and/or ALC settings on a lens. The delay depends on the feedback, that is, the electronic and mechanical combination. The electronics has its automatic gain control (AGC), but how effectively this combination works depends on the camera's electronics, including the AGC.

The combination of the two can be such that they may produce oscillation in the auto iris operation, which is usually called ringing or hunting. The ringing appears as a pulsating picture, depending on the camera viewing direction and light conditions. It is especially common when looking against strong light. To minimize it, usually level adjustment is sufficient, and sometimes ALC or both. There are unfortunate camera/lens combinations, however, where ringing cannot be eliminated. The solution is usually found in replacing the lens with that of another brand. Some newer auto iris lenses come with an additional potentiometer for adjusting the level of the lens's AGC.

As mentioned earlier, the auto iris lens cable is usually protected with a shielding that is often not connected to the auto iris. The shielding's purpose is to protect the video signal wire from picking up noise. In order for it to be effective, it is sufficient for one end of the shielding to be connected to the common of the signal electronics, which happens to be done through the lens body (the C- or CS-mount ring) and the camera C-mount thread. With camera miniaturization, the cables are getting shorter, further minimizing the risk of unwanted external noise interfering with the operation.

Finally, let's remember that the AI current consumption is very low, usually below 30 mA.

Image and lens formats in CCTV

A lens sees objects with the same angle of vision in all directions, that is, the angle of vision has a conical shape. Therefore, the image area projected by a lens has a circular shape, but the camera's sensitive area (CCD chip in our case) is a rectangle **within** the imaging circle.

In today's television, this rectangle is with the **aspect ratio of 4:3**, that is, the standard is 4 units in width by 3 units in height. As mentioned at the beginning of the book, this aspect was adopted for the film format in the early days of television.



A fixed auto iris lens

The all-new high-definition television (HDTV) system, which is already accepted with its basic standard, has an aspect ratio of 16:9. The idea is to have better movie presentations.

The "imaging rectangles" are within the image circles, which have all (or at least the majority) of the aberrations corrected.

There is no point in making a lens that produces a much bigger image circle than is required. Therefore, the lenses are made to suit the image format, no less and no more. There are exceptions, such as when lenses made for other purposes, photography, for example, are used on a CCTV camera with a special C-mount adaptor.

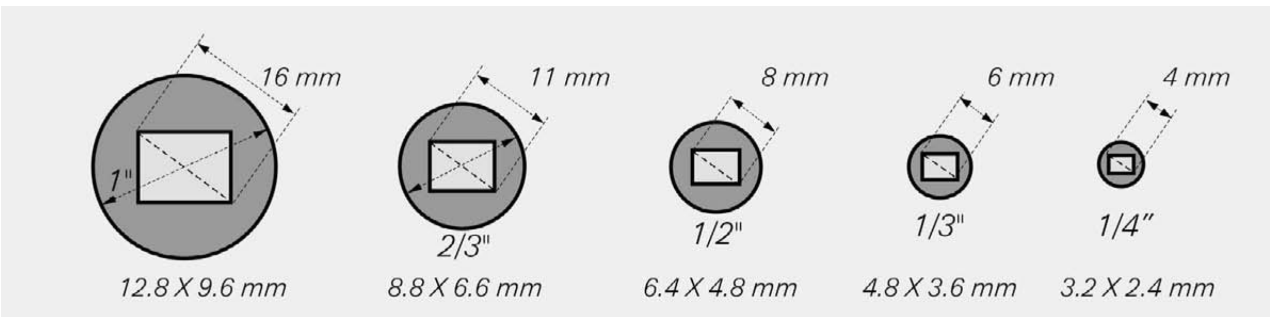
Today in CCTV, we have quite a few different chip sizes: 2/3", 1/2", 1/3", and 1/4". High-definition cameras and some

special-application cameras may have 1" or even larger chip sizes. In order to understand this variety, we should know a little bit of the history of TV.

The very first TV cameras used imaging tubes of a certain diameter and were referred to as 1" Vidicon or perhaps 2/3" Newvicon cameras. **These dimensions referred to the actual diameter of the imaging tube.** The imaging area is a rectangle with a 4:3 aspect ratio, and this rectangle has a diagonal that is **smaller** than the actual tube diameter mainly because of the tube photosensitive area (called *target*). When the electron beam scans the imaging area, it does not go to the edges of the tube. Therefore, a 2/3" tube camera has an imaging area, scanned by the electron beam, of approximately 8.8 × 6.6 mm. This area gives a diagonal length of approximately 11 mm. **This is not equal to 2/3", which, converted into millimeters, is 17 mm.** So, do not think that the CCD chip measurements are as with TV screens, where CRT size is expressed with its diagonal.

When we say a 2/3" CCD chip, we are really referring to a device that has an imaging area equal to what a 2/3" tube would have.

When the first CCTV CCD cameras were made, the common tube size was 2/3". The image area of such tubes, as mentioned previously, was 8.8 × 6.6 mm, so the CCD chips designed in those days were of the same imaging area size and they were called 2/3" chips. The idea was to use the same lenses as tube cameras did.



Various CCD chip sizes (actual size)

With the evolution of technology, CCDs were getting smaller, and the new chip size called 1/2" measured an imaging area of only 6.4 × 4.8 mm. The compatibility with the 2/3" lenses was preserved (using the same C-mount), but of course, the angle of view changed: it got smaller compared to when the same type of lens was used on a 2/3" camera.

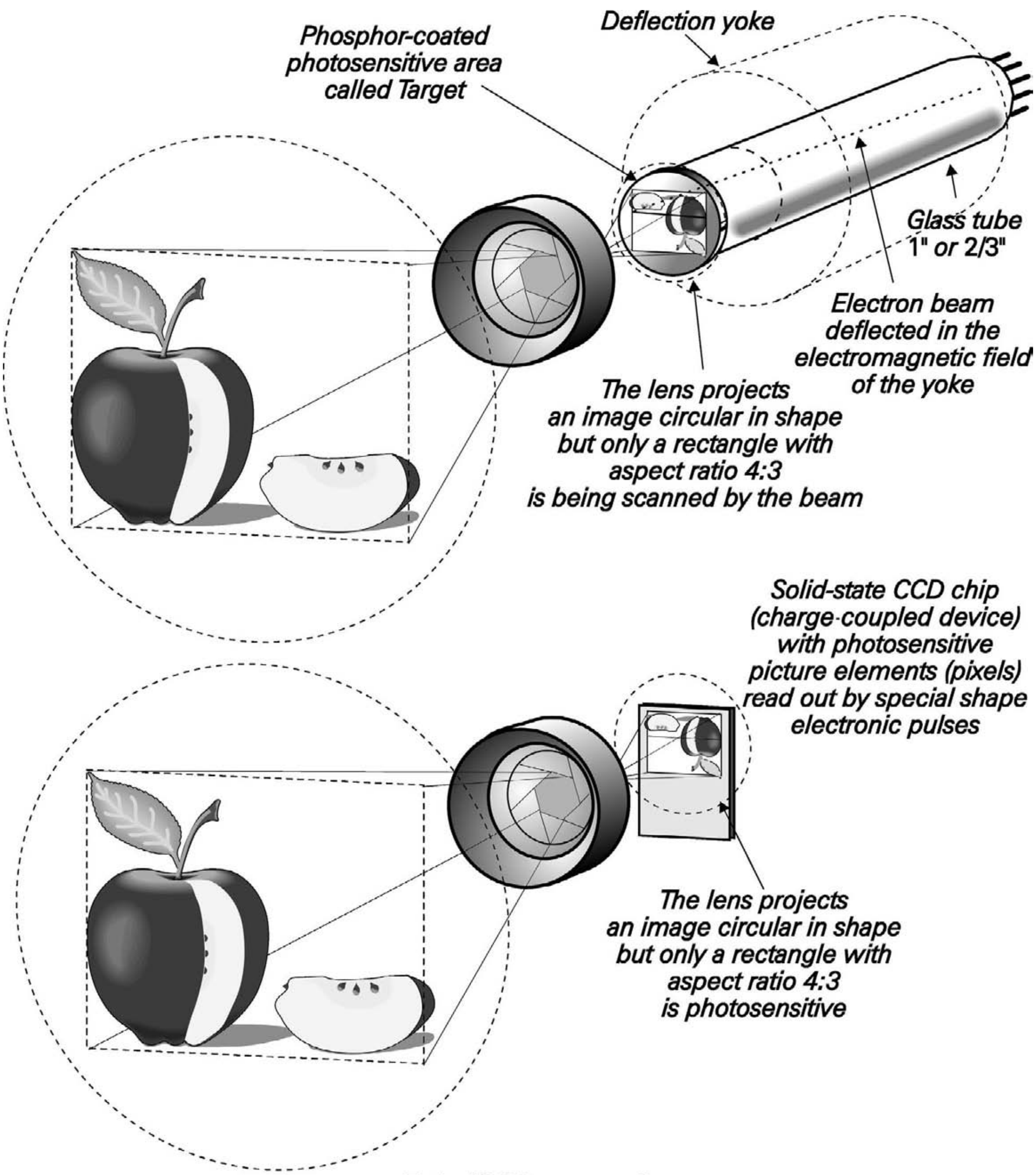
So, new lenses were designed for the 1/2" chips, which did not project as big an image as with 2/3" chips. In other words, owing to this reduction of the imaging area, lenses were designed to have the desired focal length but with a smaller imaging circle projected, that is, a circle with a diameter sufficient to cover a 1/2" chip but not necessarily 2/3". These new lenses are called 1/2" lenses. They still have the C-mount ring, but they are smaller, and consequently cheaper, than their 2/3" counterparts.

The same development is now happening with 1/3" chips, where 1/3" lenses are made to produce an image circle sufficient in diameter to cover only the 1/3" chips.

An obvious problem that will occur if a 1/3" lens is used on a 1/2" chip is that the image corners will

be cut off (imagine a rectangle and a circle with a smaller diameter drawn inside).

The same applies when a 1/2" lens is used on a 2/3" chip. There is no problem, however, if a bigger lens is used on a smaller chip. Since a lens of a bigger format will project an image circle much larger than the actual chip size, there will be no corners cut off or any other deformation.



Tube/CCD comparison

It should be taken into consideration, however, that the reduction in the imaging pickup area may result in a relative resolution reduction, since a smaller area is used (see the discussion on MTF and CTF). In addition, the excessive light around the chip (when a larger format lens is used) may get reflected inside the lens and CCD block, so if there are surfaces that are insufficiently neutralized with a black matte finish, the usable image will be affected.

Angles of view and how to determine them

Different focal length lenses give different angles of view.

We quite often use the horizontal angle of view as a reference since the vertical can be found from it, knowing that the video signal aspect ratio is 4:3, and the same applies to the horizontal vs. vertical angle of view.

There are some very basic rules to follow when analyzing the angles of view:

- The shorter the focal length, the wider the angle of view is.
- The longer the focal length, the narrower the angle of view is.
- The smaller the CCD chip, the narrower the angle of view (with the same lens) is.
- The vertical angle of view can be easily determined if the horizontal is known.

As mentioned earlier, **approximately 30° is considered a standard angle of view for whatever size the image format is**. Just to refresh our memory, 30° is taken as standard because it corresponds to our perspective impression and what the human eye sees as normal.

The following are image formats with their corresponding standard lenses for a 30° horizontal angle of view:

1" = 25 mm

2/3" = 16 mm

1/2" = 12 mm

1/3" = 8 mm

1/4" = 6 mm

In CCTV, the widest angle of view that manufacturers offer is approximately 94°, which is achieved with 4.8 mm for a 2/3" CCD camera, 3.5 mm for a 1/2", and 2.8 mm for a 1/3".

Some unique “***fish-eye***” lenses offering almost a 180° angle of view are available, but these are very specialized and show only a circular (thus the name “fish-eye”) image on the screen (within the CCD

chip image area).

Lenses do come in discrete values; that is, one cannot order any value one wants, such as 5.8 mm or 14 mm. So it is useful to know the most common focal length lenses:

2.6 mm, 3.5 mm, 4.8 mm, 6 mm, 8 mm, 12 mm, 16 mm, 25 mm, 50 mm, and 75 mm

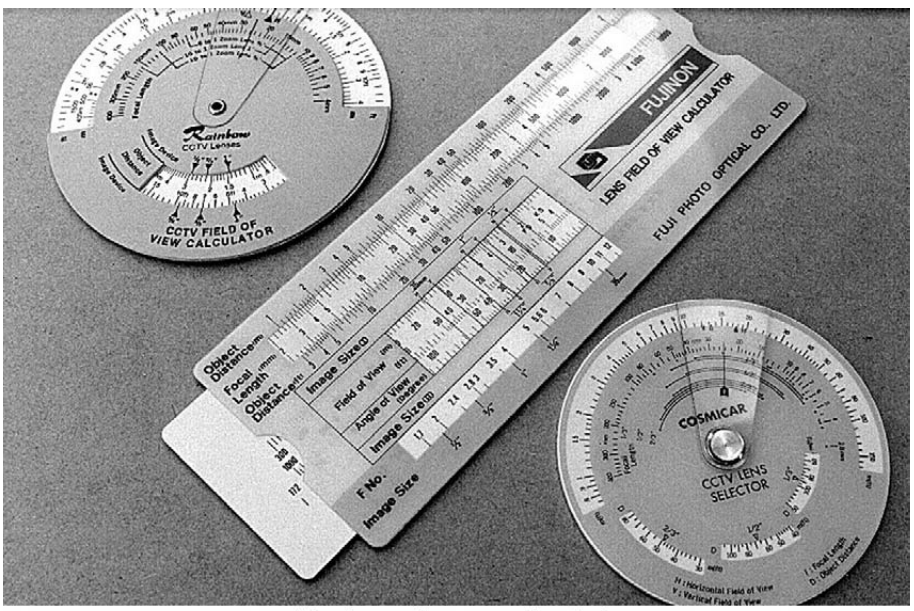
You may find some manufacturers have 3.7 mm instead of 3.5 mm, or 5.6 mm instead of 6 mm, but the values are very close and there is practically no difference in the angle of view.

The above values have horizontal angles of view that differ, more or less, in steps of 10°–15° from one to the next. These are quite sufficient to cover all practical situations, but should you really require a special focal length that is not listed above, inquire at your supplier as some manufacturers do have manually variable-focus lenses (both MI and AI) where the focal length can be varied from 6–12 mm or perhaps from 8–16 mm. The optical quality of such lenses, however, is not as good as that of fixed lenses, due to the limited precision and simplicity of the moving mechanics. But again, the quality in most cases goes with the price.

What focal length lens should be used for a particular application? This is probably the most commonly asked question when designing a CCTV system. Many techniques can be used to determine the angles of coverage, and which one you are going to use is entirely up to you, as long as the result is what your customer will be happy with.

Here is a listing of all practical methods. These are:

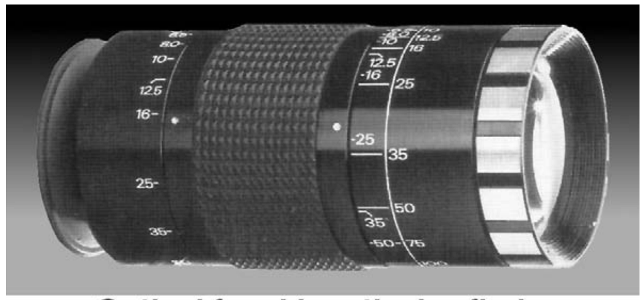
- ***Viewfinder calculator***. This is usually a circular-shaped calculator, supplied by the lens manufacturers (ask your supplier for one), where, in order to find the lens, three things need to be known: the CCD chip size, the distance between the camera and the object, and the width of the object. By adjusting these few things, the calculator should give you the focal length in mm.



Various lens calculators

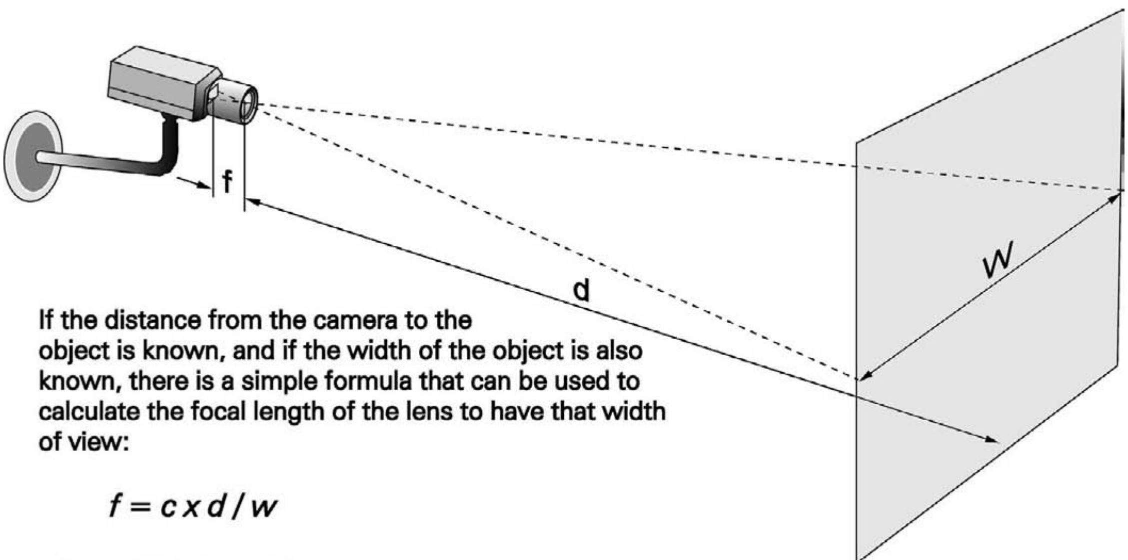
There are also ruler-shaped calculators with the same concept.

• ***Optical viewfinder***. This device looks like a zoom lens, but it is used not on a camera but by eye. When you are on site, you can manually zoom in and out and set the view to what your customer requires. A scale indicator on the viewfinder shows the focal length of the lens that will give you the same view on the particular type of camera (2/3", 1/2", or 1/3"). In order to see the same view that the camera would see, you have to position yourself close to where the camera would be installed. One little drawback with this instrument is that you cannot see the very wide angles; most of the optical viewfinders only show focal lengths down to 6 mm.



Optical focal length viewfinder

• ***Camcorder with a zoom lens***. This is quite a simple and practical method, especially these days when we have such a huge choice of camcorders with built-in zoom lenses. We need to know the chip size in the camcorder in order to refer to the same-size CCTV camera, or substitute it accordingly. Obviously, it is good to have a camcorder with a wide range of zooming, but more importantly the lens should have an indicator of each focal length at its corresponding position. When we go on site, we have the added advantage of showing our customer what the options are, and we can record and document what he or she chooses.



If the distance from the camera to the object is known, and if the width of the object is also known, there is a simple formula that can be used to calculate the focal length of the lens to have that width of view:

$$f = c \times d / w$$

***c* is the CCD chip width:**

for 2/3"= 8.8 mm
for 1/2"= 6.4 mm
for 1/3" = 4.8 mm
for 1/4"= 3.2 mm
for 1/6"= 2.4 mm

A simple "lens-find" formula

• ***A simple lens formula***. This seems the most complicated way of determining angles of view, but it is actually the simplest. This formula uses the similarity of triangles, as shown in the figure below. It is easy to understand and therefore it can be easily produced whenever necessary. The only thing you need to memorize are the CCD chip widths of the most commonly used cameras: 6.4 mm for 1/2", 4.8 mm for 1/3", and 3.4 mm for a 1/4" chip.

This formula gives you the focal length of the lens directly into millimeters.

$$f = c_{CCD} \cdot d / w_{object} \tag{34}$$

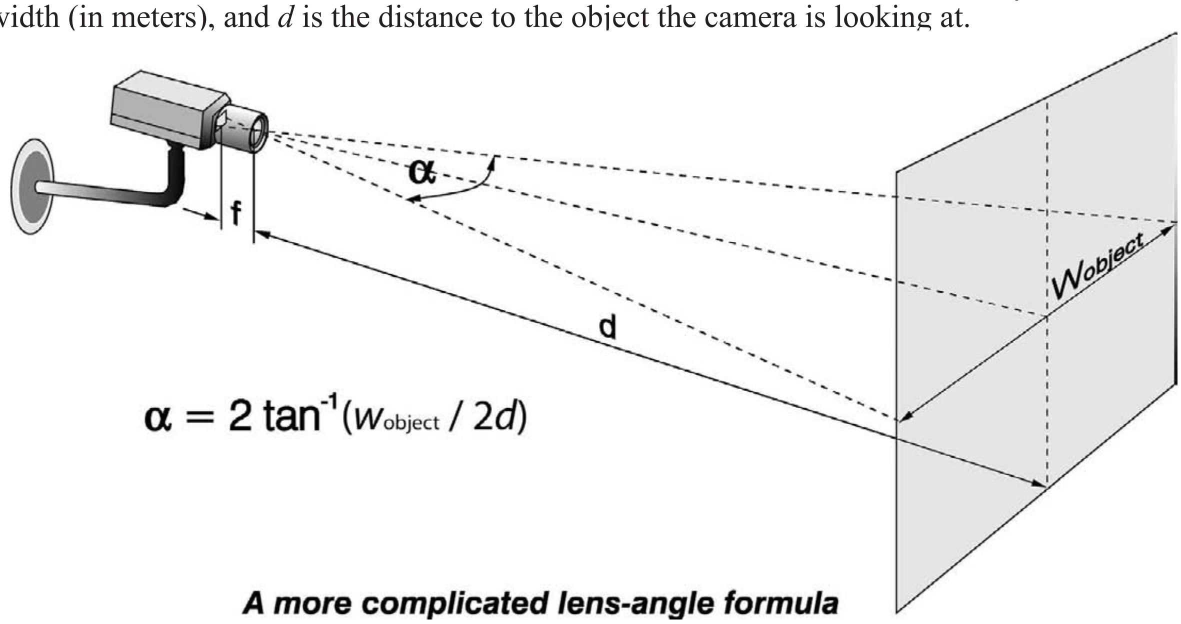
where f is the lens focal length we are looking for (in mm), c_{CCD} is the CCD chip width (in mm), d is the distance from the camera to the object (in meters), and w_{object} is the width of the object we wish to view (in meters).

The same formula can be used if we want to find what focal length lens we need, to see a certain object's height, in which case instead of w_{CCD} and w_{object} we will be working with h_{CCD} and h_{object}, where h stands for height.

• ***A more complicated formula***. This formula gives the resulting angle of view in **degrees**. It is based on elementary trigonometry and requires a scientific calculator or trigonometric tables.

$$\alpha = 2 \cdot \arctan (w_{object}/2d) \tag{35}$$

where α is the angle of view (in degrees), *arctan* is an inverse *tangent* trigonometric function (you need a scientific calculator for this), which is sometimes written as tan^{-1}, w_{object} is the object width (in meters), and d is the distance to the object the camera is looking at.



A more complicated lens-angle formula

• ***A table and/or graph.*** This is easy to use as it does not require any calculations, however, it requires a table or graph to be handy. The table on the next page gives only the horizontal angle of view for a given lens, because this is most commonly required. Vertical angles are easily found by applying the aspect ratio rule, that is, divide the horizontal angle by 4 and then multiply it by 3.

Approximate horizontal angles of view with various CCD chip sizes (in degrees)				
Focal length	2/3"	1/2"	1/3"	1/4"
2.0mm	-	-	-	82
2.8mm	-	-	86	57
4.0mm	-	77	67	47
4.8mm	83	67	57	40
6.0mm	70	56	48	32
8.0mm	56	44	36	25
12mm	39	30	25	17
16mm	30	23	17	13
25mm	18	15	12	8
50mm	10	7	6	4

In all of the above methods, we have to take into account monitor overscanning as well. In other words, most monitors do not show 100% of what the camera sees. Usually, 10% of the picture is hidden by the overscanning by the monitors. The viewfinder calculator may allow for this 10%.

Some professional monitors offer the underscanning feature. If you get hold of such a monitor you can use it to determine the amount of overscanning by the normal monitor. This is very important to know when performing camera resolution tests, as will be described later.

Fixed focal length lenses

There are two basic types of lenses (in respect to focal length) used in CCTV: ***fixed focal length*** and ***variable focal length*** (often called ***zoom***) lenses.

Fixed focal length lenses, as the name suggests, are designed with a fixed focal length, that is, giving only one angle of view. Such lenses are usually designed to have minimum aberrations and maximum resolution, so there are not many moving optical parts, except the focusing group.

The quality of a lens depends on many factors, of which the most important are the materials used (the type of glass, mechanical assembly, gears, etc.), the processing technology, and the design itself.

When manufacturers produce a certain type of lens, they have in mind its application and use. The lens quality aimed for is dictated by practical and market requirements. As mentioned previously, when

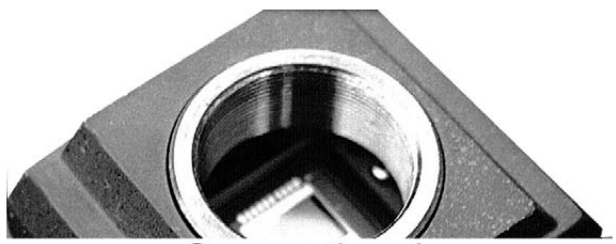


A manual iris and an auto iris lens

MTF and CTF were discussed, there is no need to go to the technical limits of precision and quality (and consequently increase the cost) if that cannot be seen by the imaging device (CCD chips in this case). This, however, does not mean that there is no difference among different makes and models of the same focal length. Usually, the price goes hand in hand with the quality.

More than two decades ago, when 1" tube cameras were used, 25 mm lenses offered a normal angle of view (approximately 30° horizontal angle).

With the evolution of the formats (that is, with their reduction), the focal length for the normal angle of view was reduced, too. The mounting thread, however, for compatibility purposes, remained the same.



C-mount thread

With the C-mount format this thread was defined as **1"-32UN-2A**, which means it is **1" in diameter with 32 threads/inch**. When the new and smaller CS format was introduced, the same thread was again kept for compatibility, although the back-flange distance was changed. This will be explained later in this chapter.

In respect to the iris, there are two major groups of fixed focal length lenses: manual iris (MI) and automatic iris lenses (AI), and these were described under the previous heading.

Finally, let us mention the vari-focal group of lenses. These lenses should be classified as fixed focal length lenses, because once they are manually set to a certain angle of view (focal length) they have to be re-focused, unlike zoom lenses, which once focused, stay in focus if the angle of view is changed.



Vari-focal lenses can be clasified as manually adjustable fixed focal lenses.

Zoom lenses

In the very early days of television, when a cameraman needed a different focal length lens, he would use a specially designed barrel, fitted with a number of fixed lenses that rotated in front of the camera. Different focal lengths were selected from this group of fixed lenses.

This concept, though practical compared to manually changing the lenses, lacked continuity of length selection, and more importantly, optical blanking was unavoidable when a selection was being made.

That is why optical engineers had to come up with a design for a continuous focal length variation mechanism, which got the popular name ***zoom***. The zoom lens concept lies in the simultaneous movement of a few groups of lenses. The movement path is obviously along the optical axis but with an optically precise and **nonlinear correlation**. This makes not only the optical but also the mechanical design very complicated and sensitive. It has, however, been accomplished, and as we all know today, zoom lenses are very popular and practical in both CCTV and broadcast television.

With a special ***barrel cam mechanism***, usually two groups of lenses (one called ***variator*** and the other ***compensator***) are moved in relation to each other so that the zooming effect is achieved **while preserving the focus** at an object. As you can imagine, the mechanical precision and durability of the moving parts are especially important for a successful zooming function.

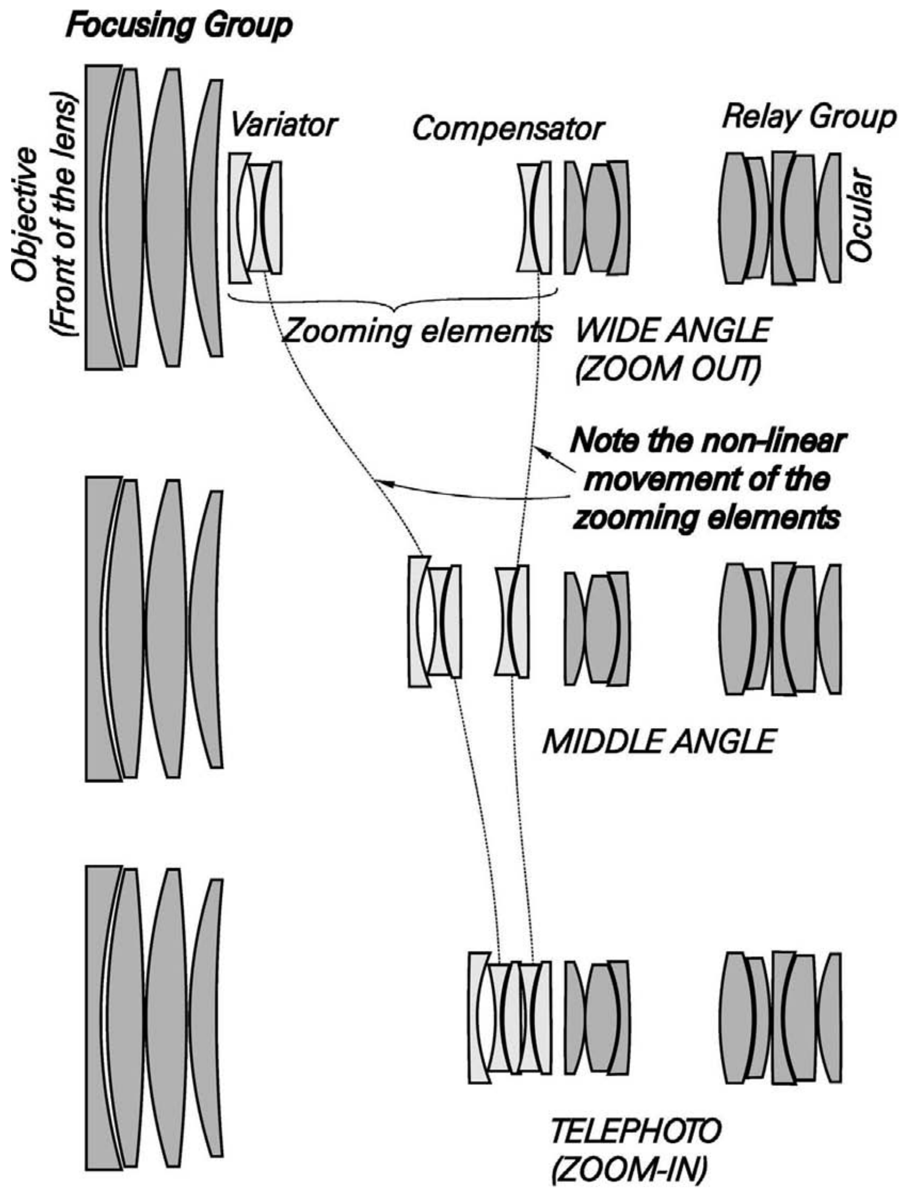
For many perfectionists in photography, zoom lenses will never be as good as fixed ones. In the absolute sense of the word this is very true because the moving parts of a zoom lens must always have some tolerance in its mechanical manufacture, which introduces more aberrations than what a fixed lens design has. Hence, the absolute optical quality of a certain focal length setting in a zoom lens can never be as good as a well-designed fixed lens of the same focal length.

For CCTV applications, however, where the CCD chip resolution is nowhere near a film structure, compromises are possible with good results. Continuous variation of angles of views, without the need to physically swap lenses, is extremely useful and practical. This is especially the case where cameras are mounted in fixed locations (as on a pole or on top of a building) and resolution requirements are not as high as with film cameras.



Photo courtesy of Cosmicar (Asahi Precision Co.Ltd.)

Zoom lenses



Zoom lenses have a complex but very precise movement of their optical elements.

It should not be assumed, however, that in their evolution zoom lenses will not come very close to the optical quality of the fixed ones.

Zoom lenses are usually represented by their ***zoom ratio***. This is the ratio of the focal length at the telephoto end of the zoom and the focal length at the wide angle end. Usually, the telephoto angle is narrower than the standard angle of vision, and the wide angle is wider than the standard angle of vision. Since the telephoto end always has a longer focal length than the wide angle, the ratio is a number larger than one.

The most popular zoom lenses used in CCTV are:

- 6×: Six times, with 6–36 mm, 8–48 mm, 8.5–51 mm, and 12.5–75 mm being the most common.
- 10×: Ten times, with 6–60 mm, 8–80 mm, 10–100 mm, 11–110 mm, and 16–160 mm as the most common examples.
- 15×: Fifteen times, with 6–90 mm, 8–120 mm.

Other ratios are available, such as 20×, or even 44× and 55×, but they are much more expensive and, therefore, not very common.



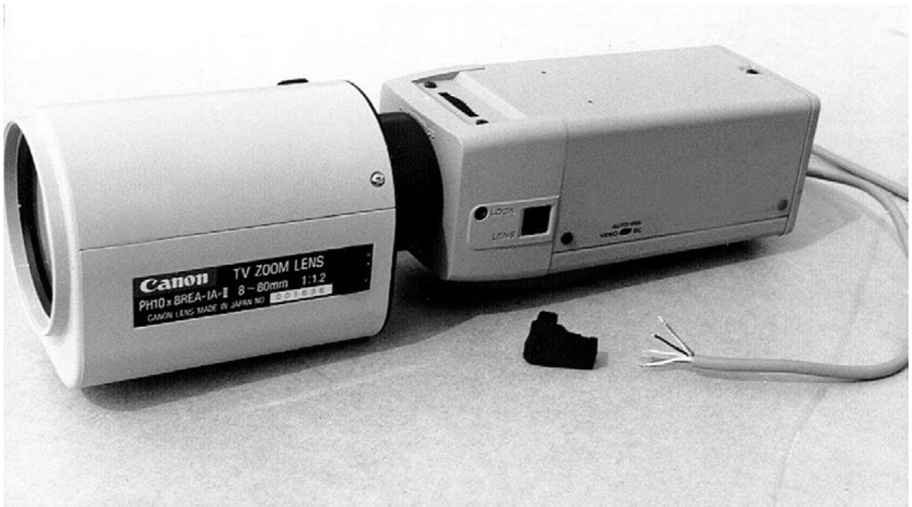
In the last five to ten years, the miniature PTZ domes have become very popular. Most of them have integral zoom lenses with optical zoom range of 12×, 16×, or even 18× zoom range. Usually, digital zooming of at least half a dozen times is added onto this, which makes these little domes extremely powerful. The digital zooming is not the same as optical, but in some cases it may help see distant objects a bit better. These PTZ dome cameras can have such powerful optical zooming, and yet look so small (the typical diameter of a PTZ dome module is around 12 cm), because they are based on 1/4" CCD chips. The smaller the chip, the smaller the optics is. This is one of the main reasons for chip reduction, besides the manufacturing cost. It should be made quite clear that the precision of manufacturing zoom lenses for 1/4" CCD chips is more demanding because of the miniaturization.

Zoom lenses are also characterized by their F-stop (or T-number). The F-stop, in zoom lenses (as already mentioned when F-numbers were discussed) refers to the shortest focal length. For example, for a 8–80 mm/1.8 lens the F-1.8 refers to the 8 mm. The F-stop is not constant throughout the zoom range. It usually stays the same with the increase of focal length only until a certain focal length is reached, after which a so-called ***F-drop*** occurs. The focal length at which this F-drop occurs depends on the lens construction. The general rule, however, is the smaller the entrance lens, the higher the likelihood of an F-drop. This is one of the main reasons lenses with bigger zoom have to have bigger front lens elements (called ***objective***), where the intention is to have a minimal F-drop.

Zoom lenses, like fixed lenses, come with manual iris, automatic iris, or motorized iris. Even though AI was explained in the previous section with fixed lenses, and because there is an additional and common subgroup with motorized iris, we will go through this again.

A ***manual iris zoom lens*** would have an iris ring, which is set manually by the installer or by the user. This is a very rare type of lens in CCTV, and it is used in special situations, such as when doing demonstrations or camera testing.

An ***automatic iris zoom lens***, often called auto iris (AI), is the most common type of zoom lens. This lens has an electronic circuit inside, which acts as an electronic-optical feedback. It is usually connected to the back of the camera where it gets its power supply (9 V DC) and its video signal. The lens's electronics then analyze the video signal level and act accordingly: if the signal exceeds the video level of 0.7 V, the lens closes the iris until a 0.7 V signal is obtained from the camera AI terminal. If, however, the signal is very low, the iris opens in order to let more light in and consequently increases the video level.



Auto iris connection of a zoom lens

Two adjustments are available for this type of lens (as with fixed lenses): **level** and **ALC**.

Level, as the name indicates, adjusts the reference level of the video signal that is used by the electronics of the lens in order to open or close the iris. This affects the brightness of the video signal. If it is not adjusted properly (that is, adequately sensitive for daylight and lowlight situations), a big discrepancy between the day and night video signals will occur. Obviously, the camera sensitivity has to be taken into account when adjusting the iris level for low light level situations.

ALC adjustment refers to the automatic light compensation of the iris. This is in fact very similar to the backlight compensation (BLC) found in many camcorders (as we have already explained in the fixed lenses section). This light compensation is usually applied when looking at scenes with very high contrast. The idea behind BLC operation is to open the iris more (even if there is a lot of light in the background) **so as to see details of the objects in the foreground.** A typical example would be when a camera is looking through a hallway (with a lot of light in the background) trying to see the face of a person coming toward the camera. With a normal lens setting, the face of the person will appear very dark because the background light will cause the iris to close. A proper ALC setting could compensate for such difficult lighting conditions. The bright background in the example above will become white, but the foreground will show details. The ALC setting actually adjusts the reference level relative to the video signal average and peak values. This is why the marks on the ALC of a lens show Peak and Average.



Auto iris zoom lens with ALC and level pots

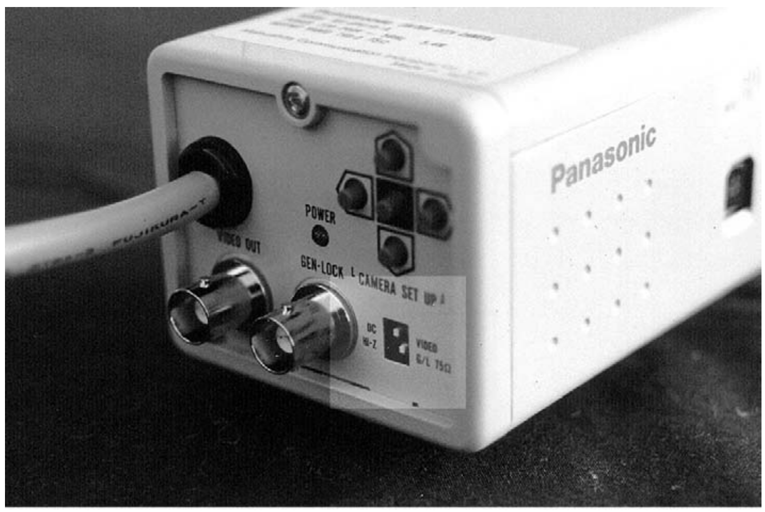
Remember that, when you strat adjusting the ALC, a very high-contrast scene needs to be viewed by the camera. If the opposite (low-contrast scene) is seen, no visible change of the video signal will occur. So, by tweaking the ALC pot in a scene with normal contrast, a misalignment may occur that will be visible only when the picture light changes.

All of the above mentioned refers to the majority of AI lenses, which are driven, as described, by the video signal picked up from the AI connector at the back of the camera. Because of this, and because there is another subgroup of AI zoom lenses that are not driven by the video signal taken from the camera, we also call this AI type ***video-driven AI***.

The other subgroup of the AI group of lenses are the ***DC-driven AI*** zoom lenses.

The DC-driven AI lenses do not have all the electronics for video processing, only the motor that opens and closes the iris. **The whole processing, in DC-driven auto iris lenses, is done by the camera's AI electronic section.** The output from such a section is a DC voltage that opens and closes the iris leaves according to the video level taken from inside of the camera. Cameras that have DC AI output also have the level and ALC adjustments, but in this case on the camera body and not on the lens.

It should be clearly noted that video-driven AI zoom lenses cannot be used with cameras that provide DC AI output, nor can DC AI be used with a video AI output camera. Some cameras can drive both these types of AI designs, in which case a switch or separate terminals are available for the two different outputs. Pay attention to this fact, for it can create problems that initially seem impossible to solve. In other words, make sure that both the camera and the lens are of the same type of AI operation.



Some cameras can "drive" both types of AI lenses.

The advantage of video-driven AI zoom lenses is that they will work with the majority of cameras. The advantage of DC-driven AI zoom lenses is that they are cheaper and are unlikely to have the "hunting" effect as the camera processes the gain. The disadvantage is that not all cameras have a DC-driven AI output. To date, video-driven AI lenses are more common.

Motorized iris lenses belong to the third lens subgroup, if selection on the basis of the iris function is made. This is an iris mechanism that can be controlled remotely and set by the operator according to the light conditions. This type of zoom lens has become increasingly popular in the last few years, especially with the development of CCD-iris cameras.

In order to open or close the iris, instead of an AI circuit driving the iris leaves, a DC voltage, produced by the PTZ site driver, controls the amount of opening or closing. PTZ site drivers will be explained

later in Chapter 12, but to put it very simply they are boxes with electronics that are capable of receiving encoded digital data for the movement of the Pan/Tilt head, as well as the zoom lens functions, and converting it into voltage that actually drives the PTZ assembly. In the case of motorized iris lenses, the PTZ site driver has to have an output to drive the iris as well.

With the CCD-iris camera it is better to have this type of lens iris control than an automatic one. The CCD-iris (electronic function of the CCD chip) is a faster and more reliable light-controlling section of the camera, but it **does not substitute the depth of field** effect produced by the high F-stops of an optical iris. **Optical and electronic irises cannot function properly if they are working simultaneously**. The video camera usually balances with a low F-stop (high iris opening), which results in a very narrow depth of field, and a high electronic shutter speed, which produces a less efficient charge transfer (that is, high smear). This is especially obvious when such a camera/lens combination comes across a high-contrast scene. To avoid a low-quality picture, and yet use the benefits of a fast and reliable CCD-iris function, and even more, have depth of field, motorized iris lenses are the solution. It will obviously require an operator's intervention, but that does not have to happen until the picture demands it, since the CCD-iris will be functioning constantly to compensate for the abrupt light variations.

When ordering zoom lenses, you are expected to specify whether you want a motorized iris lens; otherwise, the manufacturer may supply you with a standard video-driven AI zoom lens as they are the most common.

And finally, let us mention the ***vari-focal*** lenses again. Vari-focals do not have the same functionality as the zoom lenses. Their classification should be in the fixed focal lenses group. They will be practical in cases where the customers do not know what angle of coverage they require, but they have to always be manually re-focused once the angle of view (that is, the focal length) is changed.

A note of warning: be more critical of the optical quality of vari-focal lenses. It is more difficult to produce the same optical resolution due to additional movement when compared to fixed focal lenses. Of course, in some situations vari-focals may have quite sufficient quality for the application, but trials will always give you a better judgment.

C- and CS-mount and back-focus

"***Back-focusing***" is what we call the adjustment of the lens back-flange relative to the CCD image plane. Back-focusing is very important in CCTV. Currently, there are two standards for the distance between the back-flange of a lens and the CCD image plane:

- ***C-mount***, represented with 17.5 mm (more precisely, 17.526 mm).

  This is a standard mounting, dating from the very early days of tube cameras. It consists of a metal ring with a 1.00/32 mm thread and a front surface area at 17.5 mm away from the image plane.

- ***CS-mount***, represented with 12.5 mm.

  This is a new standard intended for smaller camera and lens designs. It uses the **same thread** of

1.00/32 mm as the C-mount, but it is approximately 5 mm closer to the image plane. The intention is to preserve compatibility with the old C-mount format lenses (by adding a 5 mm ring) and yet allow for cheaper and smaller lenses, to suit smaller CCD chip sizes, to be manufactured.

Since both of the above formats use the thread type of lens mounting, there might be small variations in the lens's position relative to the CCD chip when mounted (screwed in), hence the need for a little variation of this position (back-focus adjustment).

In photography, for example, we never talk about back-focusing simply because most of the brands come with a bayonet mount, which has **only one fixed position of the lens relative to the film plane**. Camcorders, for that matter, come with lenses as an integral part of the unit, so the back-focus is already adjusted and never changes.

In CCTV, because of the modular concept of the camera/lens combination and the thread mount, it is a different story.

Back-focus adjustment is especially important and critical when zoom lenses are used. This is because the optics-to-CCD distance in zoom lenses has to be very precise **in order to achieve good focus throughout the zoom range**.



If a lens is C-mount and the camera is CS, a C/CS adaptor ring is required.

Obviously, the back-focusing adjustment applies to fixed lenses as well, only in that case we tend not to pay attention to the distance indicator on the lens ring when focusing. If we want to be more accurate, when the back-focus is adjusted correctly on a fixed lens, the distance indicator should show the real distance between the camera and objects. Most installers, however, do not pay attention to the indicator on the lens since all they want to see is a sharp image on the monitor. And this is fine, but if we want to be precise, the back-focus adjustment should apply to **all** lenses used in CCTV. With zoom lenses this is more critical.

An important factor to be taken into account when doing back-focus adjustment is the effect of depth of field. The reason is very simple: if a CCTV camera is installed at daytime (which is most often the case) and if we are using an AI lens, it is natural to see the iris set at a high F-stop to allow for a good picture (assuming the AI is connected and works properly). Since the iris is at a high F-stop, we have a very high depth of field. The image seems sharp no matter where we position the focusing. At nighttime, however, the iris opens fully owing to the low light level situation, and the operator sees the picture out of focus.

This is actually one of the most common problems with new installations. When a service call is

placed, usually the installer comes during the daytime to see what the problem is, and if the operator cannot explain exactly what he or she sees, the problem may not be resolved, since the picture looks great with a high F-stop.



Some cameras don't require C/CS adaptor.

The moral of the above is: always do the back-focus adjustment with a low F-stop (largest lens iris opening).

How do you make the iris open to maximum? The following different methods are used:

- Adjust the back-focus at low light levels in the workshop (easiest).
- Adjust the back-focus in the late afternoon, on site.
- Adjust the back-focus at daytime, on site, by using external ND filters.

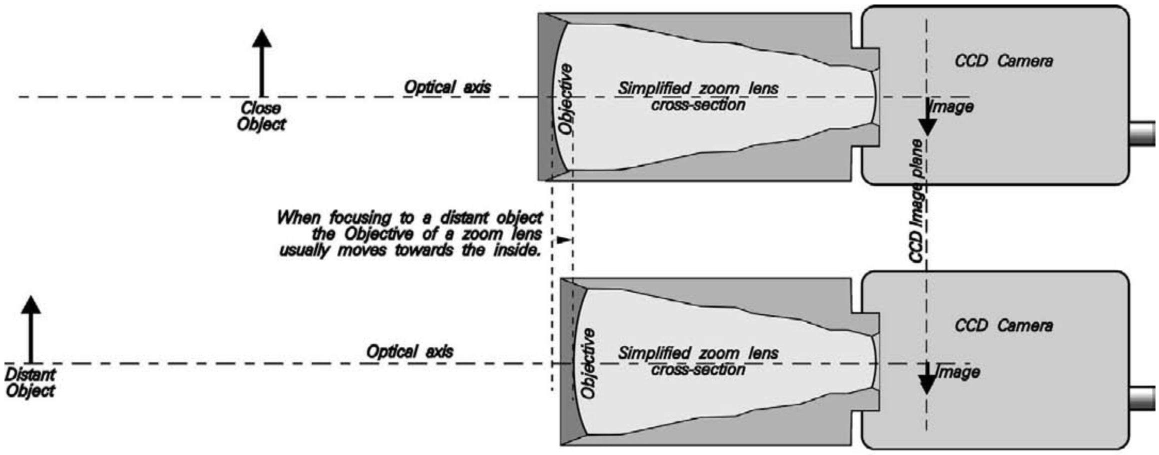
There is one exception to the above: if a camera with CCD-iris is used, then the optical iris can be opened fully even at daylight because the CCD-iris will compensate for the excessive light. This means that with CCD-iris cameras, the back-focus can easily be adjusted even at daylight without being confused with the depth of field and without a need for ND filters. Obviously, you should not forget to switch the CCD-iris off after the adjustment, should you decide to use auto iris.

Back-focus adjustment

In the following few paragraphs we will examine a procedure for proper back-focus adjustment. This discussion is based on practical experience and by no means the only procedure, but it will give you a good understanding of what is involved in this operation. We should also clarify that often, with a new camera and zoom lens setup, there might not be a need for back-focus adjustment. This can be easily checked as soon as the lens is screwed onto the C or CS ring, and the camera is connected to a monitor. Obviously, the zoom and focus functions have to be operational so that one can check if there is a need for adjustment. The idea is to get as sharp an image as possible, and if a zoom lens is used, once it is focused on an object, the object should stay in focus no matter what zooming position is used. If this is not the case, then there is a need for back-focus adjustment.

One will rightly ask: "What is so complicated about adjusting the back-focus?"

The answer is of a rather practical nature and is apart from the depth-of-field problems. The reason for



Zoom lens focusing at different distance objects

this is that no zoom lens in CCTV comes with a distance indicator engraved on the lens. For example, if a zoom lens had a distance indicator engraved, we could set the focus ring to a particular distance, then set an object at that distance, and adjust for a perfectly sharp image (a monitor, of course, is required) while rotating the lens **together** with the C-mount ring, or perhaps adjusting the CCD chip back and forth by a screw mechanism on the camera. But, of course, the majority of zoom lenses do not come with these distances engraved, so the hard part is to determine the starting point.

All lenses have two known points on the focus ring (the limits of the focus ring rotation):

- Focus infinity "∞" (no lens focuses past this point)
- Focus at the minimum object distance (MOD)

The second point varies with different lenses, that is, we do not know what the minimum focusing distance of a particular lens will be, unless we have the manufacturer's specification sheet, which is usually not supplied with the lens or, quite often, is lost in the course of installation.

This leaves us with only the focus infinity as a known point. Obviously, infinity is not literally an infinite distance, but it is big enough to give a sharp image when the lens is set to the "∞" mark.

The longer the focal length of the lens, the longer the infinity distance that has to be selected. For a typical CCTV zoom lens of 10× ratio, which is usually 8–80 mm, 10–100 mm, or 16–160 mm, this distance may be anything from 200–300 m onward. From this, we can see it is impossible to simulate this distance in the workshop, so the technician working on the back-focus needs to point the camera out through a window, in which case ***external ND filters*** are required to minimize the effect of depth of field (unless a CCD-iris camera is used, of course).

The next step would be to set the focus to the infinity mark. To do this, a PTZ controller would be required, but this is obviously impractical.

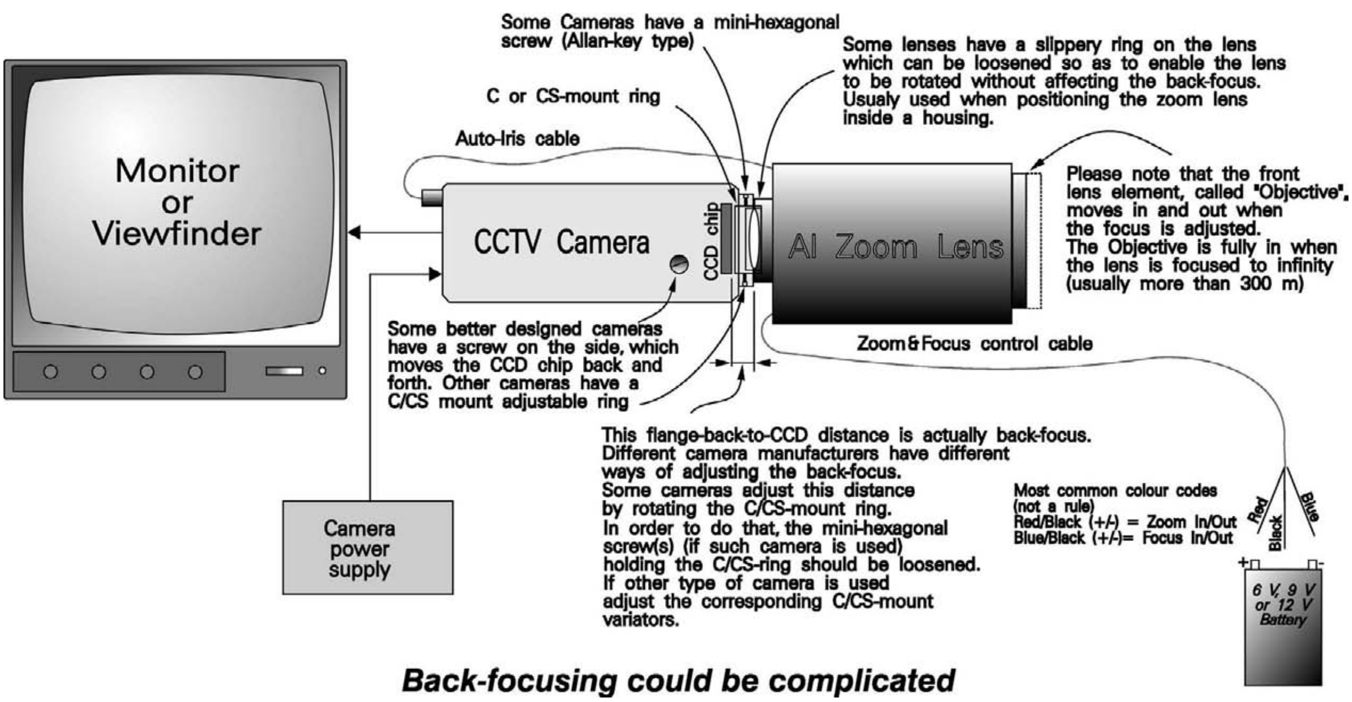
I suggest, therefore, simulating the zoom and focus control voltages by using a regular 9 V DC battery

and applying it to the focus and zoom wires. Do not forget, the lens focus and zoom control voltages are from ±6 V DC to ±9 V DC, and the lens has a very low current consumption, usually below 30 mA. A 9 V battery has plenty of capacity to drive such motors for a considerable time, at least long enough for the adjustment procedure to be completed.

There is no standard among manufacturers for the lens wire color coding, but quite often, if no information sheet is supplied with the lens, the black wire is common, the zoom wire is red, and the focus wire is blue. This is not a rule, so if in doubt it is not that difficult to work it out by using the same battery and monitor. Instead of a monitor, an even more practical tool would be a **viewfinder**; some call it a focus adjuster. This is a little monitor that is battery operated, with a rubber eyepiece to protect from excessive daylight. On a bright sunny day, if a normal monitor is used in the field, it will be almost impossible to see the picture on the screen, so it is highly recommended that you use a viewfinder instead.

If no monitor is available at the point of adjustment, a distinction should be made between which optical parts move when focusing and which when zooming. This is not so naive, since zoom lenses are enclosed in black (or beige) boxes and no moving parts are visible. A rule of thumb, however, would be zooming elements are not visible from the outside, while focusing is performed by the first group of lenses, called the ***objective***. When focusing is done, the objective rotates around its optical axis and at the same time moves along the optical axis toward either the inside or the outside of the lens. All lenses have this common concept of the objective moving toward the outside when focusing to closer distances, and moving toward the inside of the lens when focusing to infinity. See the section on the focusing concepts, on page 64, for an explanation.

So, even if the zoom lens does not have any visible markings for distances and zoom factors, using the above logic we can start doing the back-focus adjustment.



Back-focusing could be complicated

With the battery applied to the focus wire we need to focus the lens to infinity. Even if we do not have a monitor, this will be achieved when the **lens objective goes to the end position on the inside of the lens**.



On-camera C/CS ring

The next step is to point the camera to an infinity object, at a distance we have already mentioned. The infinity objects can be trees or antennas on the horizon.

Now, without changing the focus, zoom in and out fully. If the picture on the monitor looks sharp throughout the zooming range, **back-focusing is not necessary.**

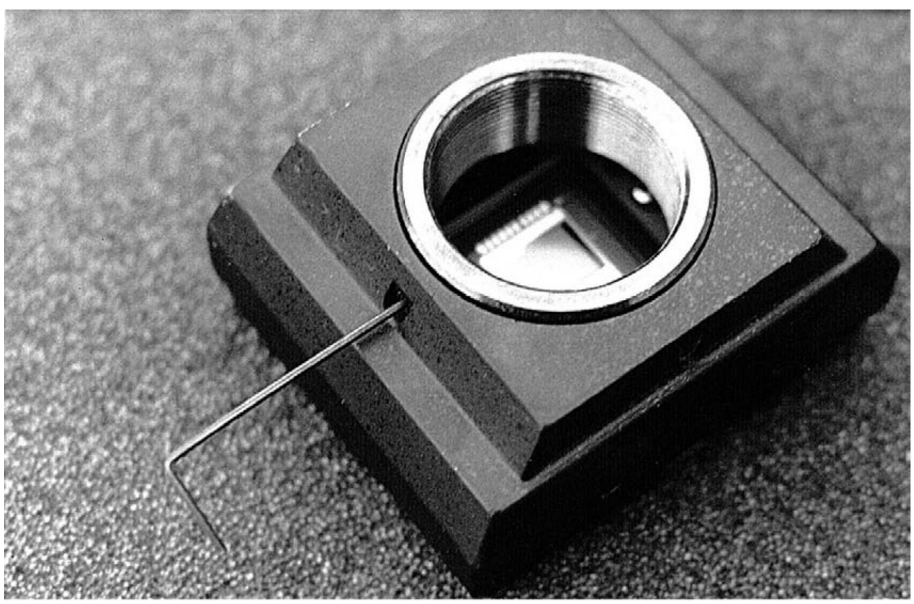
If, however, the camera's C- or CS-mount ring is out of adjustment, we will not see a sharp picture on the monitor for all positions of the zoom.

Then, we proceed with adjustment by either rotating the lens together with the C-ring (if the camera is of such a type) or by shifting the CCD chip with a special back-focus adjustment screw or in some cameras by rotating a large ring with C & CS written on it.

The first type of camera is the most common. In this case, the C- or CS-mount ring is usually secured with miniature hexagonal locking screws. These need to be loosened prior to the adjustment but after the zoom lens is screwed in tightly.

Then, when the focus is to be adjusted (after we did the battery focusing and pointing to infinity) we need to rotate the zoom lens but now **together** with the ring (that is why we have loosened the ring). Again, some cameras may have a special mechanism that shifts the CCD chip back or forth, in which case it is easier since we do not have to rotate the lens.

By doing one of the above, the distance between the lens and the CCD chip changes until the picture becomes sharp. Do not forget, because we have made the depth of field minimal by opening the iris as much as possible (with low light level simulation), the sharpness of the objects in the distance should be quite easily adjusted. Once we find the optimum we should stop there.



Some CCD cameras use miniature hexagonal screws to secure the C-mount ring to the camera.

Please note that the focus wires are not used yet; that is, we still need to have the zoom lens focused at infinity. We are only making sure that while zooming, the lens stays focused at infinity throughout the zoom range. Also, we need not be confused when the objects at infinity are getting smaller while zooming out; because of the image size reduction, they might give the impression that they are going out of focus.

The next step would be to zoom by using the 9 V battery. Watch the video picture carefully and make sure that the objects at infinity stay in focus while zooming in or out. If this is the case, our back-focus is nearly adjusted.

In order to confirm this, the next step would be to point the camera at an object that is only a couple of meters away from the camera. Then we zoom in on the object and use the focusing wires to focus on it. When focused precisely, use the zoom wires and zoom out. If the object stays in focus, that will be **confirmation** of a correct back-focus adjustment.

The last step would be to tighten the little hexagonal screws (if such a camera is used) and secure the C/CS mount ring on the camera.

If the above procedure does not succeed from the very first go, a couple of iterations might be necessary, but the same logic applies.

As one can imagine, the mechanical design and robustness of the C-mount CCD-chip combination is very important, especially the precision and "parallelness" of the C-ring and the CCD chip plane. Little variations of only one-tenth of a millimeter at the image plane may make a focus variation of a couple of meters at the object. With bad designs, such as locking the C-ring with only one screw or poor mechanical construction, problems might be experienced even if the above procedure is correct. So it is not only the lens that defines the picture quality, but the camera's mechanical construction as well.

We have mentioned that a monitor is required when doing the back-focus adjustment, which is not a surprise. This is fine when the adjustments are done in the workshop, but when back-focusing needs to be performed on site it is almost impossible to use a normal CRT monitor. The reason for this is not so much the impracticality of the need for a main supply (240 VAC or whatever the country you are in has), but more so because of the bright outdoor light compared to the brightness produced by a CRT monitor. This is why I have recommended the use of a viewfinder monitor (like the ones used on camcorders) with a rubber eyepiece that protects from external light and allows for comfortable use. In addition, these little viewfinder monitors are battery operated and very compact. Some manufacturers have viewfinder focus adjusters specially made with a flicker indicator to show when objects are in focus.



Focus-adjusting tool

Small and practical tools like this one make the difference between a good and bad CCTV system installation and/or commissioning.

Optical accessories in CCTV

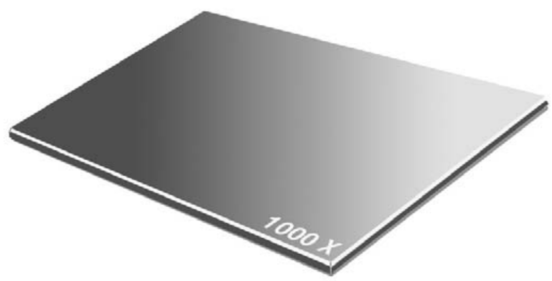
Apart from fixed and zoom lenses in CCTV, we also have some optical accessories.

One of the more popular is the ***2× teleconverter*** (also known as an ***extender***). The teleconverter is a little device that is usually inserted between the lens and the camera. The 2× converter multiplies the focal length by a factor of 2. In fact, this means a 16 mm lens will become 32 mm, a zoom lens 8–80 mm will become 16–160 mm, and so on. It is important to note, however, that the F-number is also increased for one F-stop value. For example, if a 2× converter is used on a 16 mm/1.4, this becomes 32 mm/2. Back-focusing a lens with a 2× converter may be more complicated. It is recommended that you first do the back-focusing of the zoom lens alone, and then just insert the converter. Some zoom lenses come with a teleconverter built-in but removable with a special control voltage. For this purpose the auxiliary output from a site driver can be used. In general, the optical resolution of a lens with a converter is reduced, and if there is no real need for it, it should be avoided. It should be noted that 1.5× converters also exist.



Optical accessories Photo courtesy of Fujinon

Another accessory device is the ***external ND filter***, which comes with various factors of light attenuation – 10×, 100×, or 1000×. They can also be combined to give higher factors of attenuation. As we have already described, external ND filters are very helpful in back-focusing and AI adjustments. Since they come as loose pieces of glass, you may have to find a way of fixing them in front of the lens objective. Some kind of a holder could be made for better and more practical use of the filters.



A 100X neutral density filter

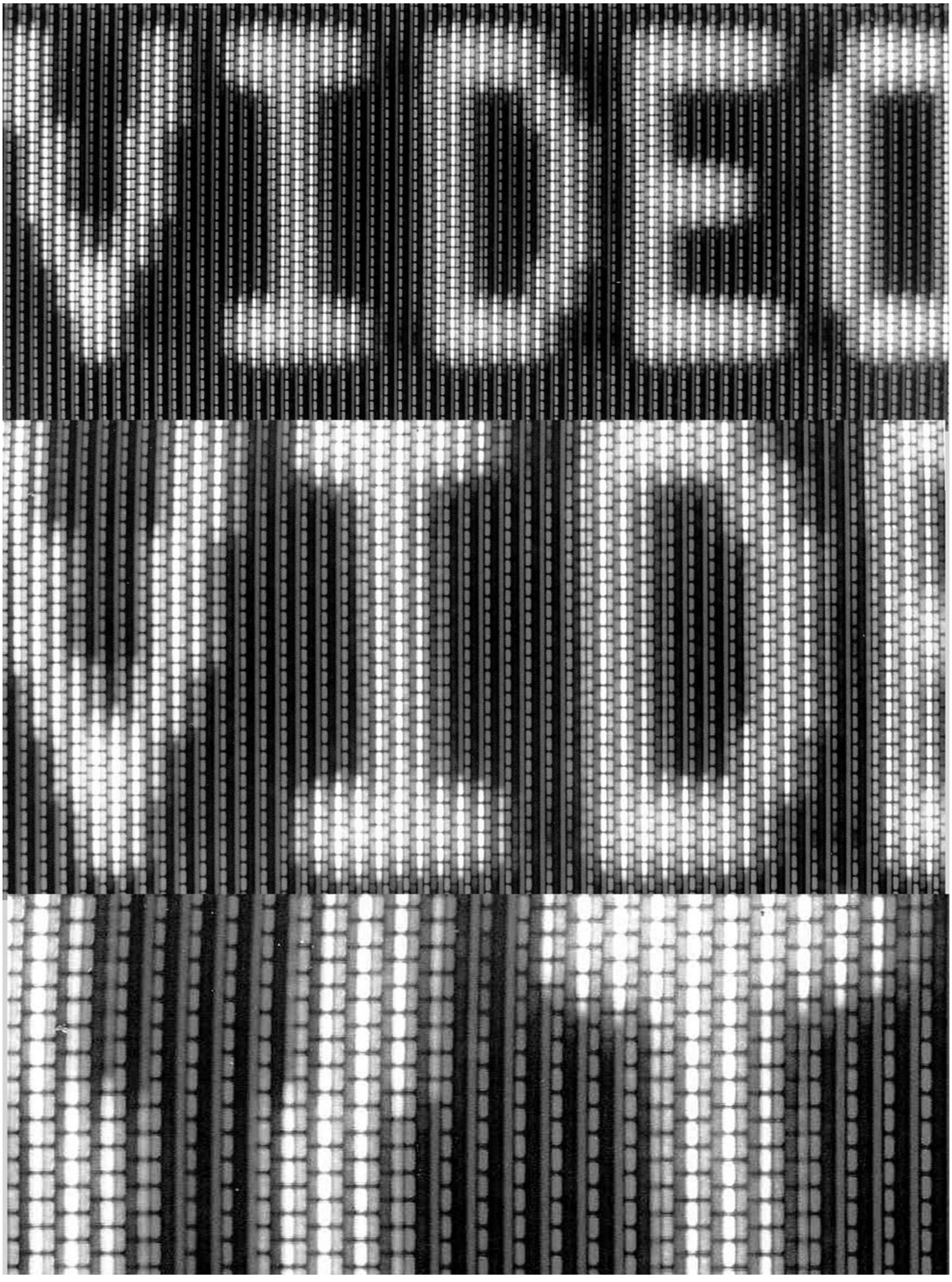
Polarizing filters might sometimes be required when using a CCTV camera to view through a window or water. In most cases, reflections make it difficult to see what is beyond the glass or water surface. Polarizing filters can minimize such an effect. However, there is little drawback in the practicality of this, since a polarizing filter requires rotation of the filter itself. If a fixed camera is looking at a fixed area that requires a polarizing filter, that might be fine, but it will be impossible to use it on a PTZ (pan/tilt/zoom) camera because of constant camera repositioning and objective rotation when focusing.

For special purposes, when the camera needs to have a close-up (macro) view of a very small object, it is possible to focus the lens on objects much closer than the actual MOD (Minimum Object Distance)

as specified by the lens manufacturer. This can be achieved with special sets of ***extension rings*** that can be purchased through some lens suppliers. It is much easier and also more practical to use surplus CS-mount adaptor rings. By combining one or more of them, and depending upon the focal length in use, macro views can be obtained. This might be useful for inspecting surface mount PCB components and stamps, detecting fake money, and monitoring insects or other miniature objects.



Extension rings



4. General characteristics of television systems

This chapter discusses the theoretical fundamentals of video signals, their bandwidth and resolution. It is intended for technical people who want to know the limits of the television system in general and CCTV in particular.

A little bit of history

In order to understand the basic principles of television, we have to refer to the effect of eye persistence (see Chapter 2).

Television, like cinema, uses this effect to cheat our brain, so that by showing us still images at a very fast rate, our brain is made to believe that we see “motion pictures.”



Baird’s television receiver, 1923

In 1903, the first film shown to the public was *The Great Train Robbery* which was produced in the Edison Laboratories. This event marked the beginning of the motion picture revolution. Although considered younger than film, the concept of television has been under experimentation since the late nineteenth century. It all began with the discovery of the element selenium and its *photoelectricity* in 1817 by the Swedish chemist Jons Berzelius. He discovered that the electric current produced by selenium, when exposed to light, would depend on the amount of light falling onto it. In 1875, G.R. Carey, an American inventor, made the very first crude television system, in which banks of photoelectric cells were used to produce a signal that was displayed on a bank of light bulbs, every one of which emitted light proportional to the amount of light falling onto the photo cells. A few minor modifications were made to this concept, such as the “scanning disk” presented by Paul Nipkow in 1884, where elements were scanned by a mechanical rotating disk with holes aligned in a spiral. In 1923, the first practical transmission of pictures over wires was accomplished by John Baird in England and later Francis Jenkins in the United States of America. The first broadcast was transmitted in 1932 by the BBC in London, while experimental broadcasts were conducted in Berlin by the Fernseh Company, led by the cathode ray tube (CRT) inventor Professor Manfred von Ardenne. In 1931, a Russian born engineer, Vladimir Zworykin, developed the first TV camera known as the iconoscope, which had the same concept as the later developed tube cameras and the CRT.



Zworykin’s iconoscope

Both of these technologies, film and TV, produce many static images per second in order to achieve the motion effect. In TV, however, instead of projecting static images with a light projector through a celluloid film, this is achieved with electronic beam scanning. Pictures are formed line by line, in the same manner as when reading a book, for example, from left to right and from top to bottom (as seen from in front of the CRT). The persistency of the phosphor coating of the monitor's CRT is playing an important role in the whole process.

The very basics of television

There are a few different television standards used worldwide today. CCIR/PAL recommendations are used throughout most of Europe, Australia, New Zealand, most of Africa, and Asia. A similar concept is used in the EIA/NTSC recommendations for the television used in the United States, Japan, and Canada, as well as in the SECAM recommendations used in France, Russia, Egypt, some French colonies, and Eastern European countries. The major difference between these standards is in the number of scanning lines and frame frequency.

Before we begin the television basics, let us first explain the abbreviation terminology used in the technical literature discussing television:

CCIR stands for ***Committée Consultatif International des Radiotelecommuniqué***. This is the committee that recommended the standards for B/W television accepted by most of Europe, Australia, and others. Hence we call equipment that complies with the B/W TV standards **CCIR compatible**. The same type of standard, but later extended to color signals, was called **PAL**. The name comes from the concept used for the color reproduction by alternate phase changes of the color carrier at each new line – hence, ***Phase Alternating Line*** **(PAL).** Majority of CCIR/PAL systems are based on 625 scanning lines and 50 fields/s, although there are variations with 525 lines.

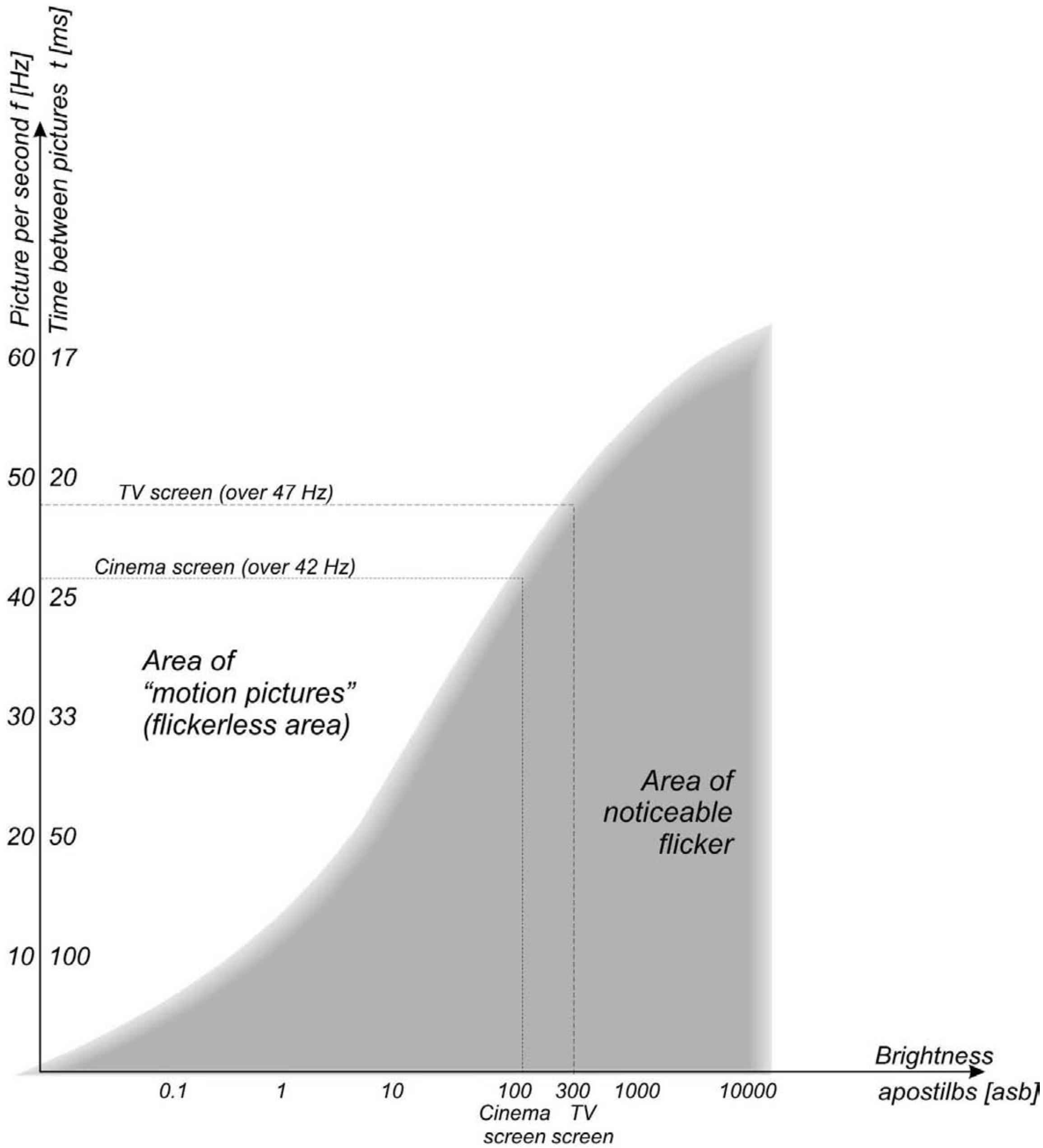
EIA stands for ***Electronics Industry Association***, an association that created the standard for B/W television in the United States, Canada and Japan, where it is often referred to as **RS-170**, the recommendation code of the EIA proposal. When B/W TV was upgraded to color, it was named by the group that created the recommendation: ***the National Television Systems Committee*** **(NTSC)**. The EIA/NTSC systems are based on 525 scanning lines and 60 fields/s.

SECAM comes from the French "***Séquentiel Couleur avec Mémoire***" which actually describes how the color is transmitted by a sequence of chrominance color signals and the need for a memory device in the TV receiver when decoding the color information. Initially patented in 1956 by Henri de France, the SECAM was actually the first analog color television proposal, based on 819 lines and 50 fields/s. Later on, SECAM switched to 625 lines.

All of the TV standards' recommendations have accepted the picture ratio of the TV screen to be 4:3 (4 units in width by 3 units in height). This is due mostly to the similar film aspect ratio of the early days of television. The different number of lines used in different TV standards dictates the other characteristics of the system, such are the signal bandwidth and resolution.

Regardless of these differences, all of the systems use the same concept of composing pictures with electron beam scanning lines, one after another.

When a video signal, as produced by a camera, comes to the monitor input, the voltage fluctuations are converted into current fluctuations of electrons in the electron beam that bombards the phosphor coating of the ***cathode ray tube*** (CRT) as it is scanning line by line. The phosphor coating produces light proportional to the amount of electrons, which is proportional to the voltage fluctuation. This is, of course, proportional to the light information falling onto the camera CCD chip, thus, the monitor screen shows an image of what the camera has seen.



Persistency curve of the human eye

The phosphor coating of the monitor has some persistency as well – light produced by the beam does not immediately disappear with the disappearance of the beam. It continues to emit light for another few milliseconds. This means the TV screen is lit by a bright stripe that moves downward at a certain speed.

This is obviously a very simplified description of what happens to the video signal when it comes to the monitor. We will discuss monitor operation in more detail in Chapter 6, but we will use the previous information as an introduction to the television principles for the readers who do not have the technical background.

Many factors need to be taken into account when deciding the number of lines and the picture refresh rate to be used. As with many things in life, these decisions have to be a compromise – a compromise between as much information as possible, in order to see a faithful reproduction of the real objects, and as little information as possible, in order to be able to transmit it economically and receive it by a large number of users who can afford to buy such a TV receiver.

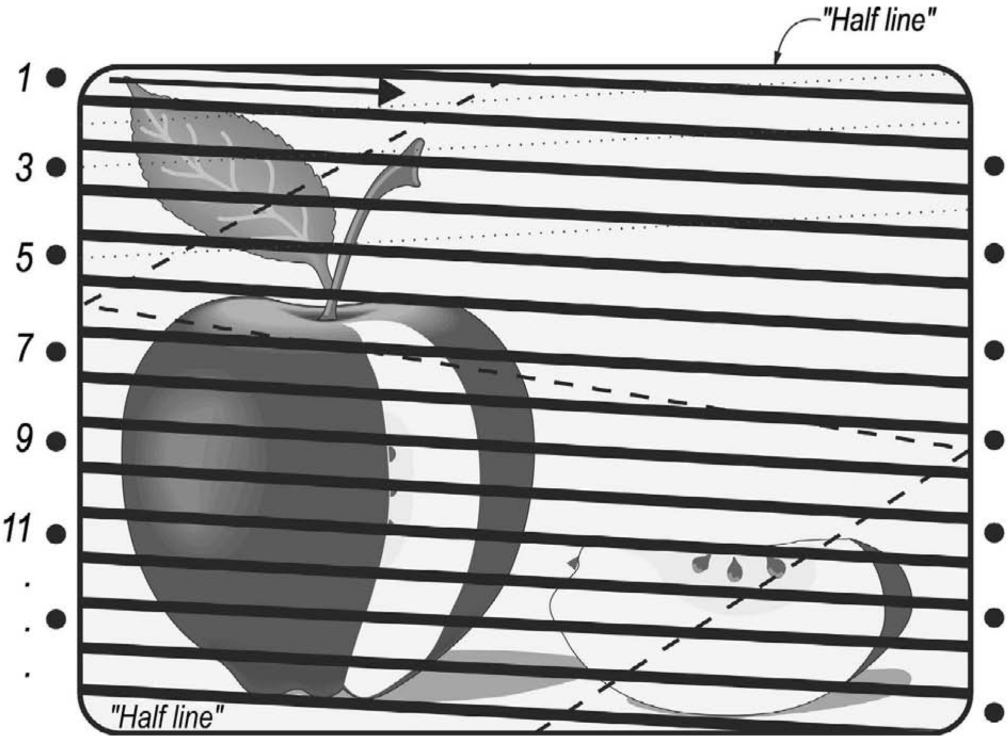
The more lines used, combined with the number of pictures per second, the wider the frequency bandwidth of the video signal will be, thus dictating the cost of the cameras, processing equipment, transmitters, and receivers.

The refresh rate, that is, the number of pictures composed in 1 second, was decided on the basis of the persistence characteristic of the human eye and the luminance of the CRT. Theoretically, 24 pictures per second would have been ideal because of the compatibility between cinematography and television (used widely at the time of television's beginning). Practically, however, this was impossible because of the very high luminance produced by the phosphor of the CRT, which led to the flicker effect which depends on the viewing distance and the screen luminance, as shown on the diagram on the previous page.

With many experiments it was found that at least 48 pictures per second were required for the flicker to be eliminated. This would have been a good number to use because it was identical to the cinema projector frequency and would be very practical when converting movies into television format. Still, this was not the number that was accepted. The television engineers opted for 50 pictures per second in CCIR and 60 in EIA recommendations. These numbers were sufficiently high for the flicker to be undetectable to the human eye, but more importantly they coincided with the mains frequency of 50 Hz used all over Europe and 60 used in the United States, Canada, and Japan. The reason for this lies in the electronic design of the TV receivers that were initially very dependent on the mains frequency. Should the design with 48 pictures have been accepted, the 2 Hz difference for CCIR and 12 Hz for EIA, would have caused a lot of interference and irregularities in the scanning process.

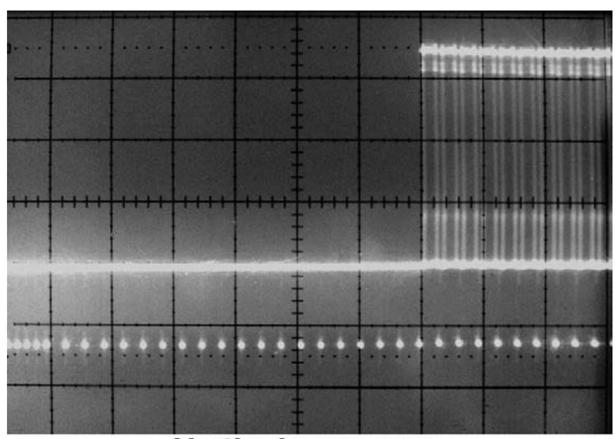
The big problem, though, was how to produce 50 (PAL) or 60 (NTSC) pictures per second, without really increasing the initial camera scan rate of 25 (that is 30) pictures per second. Not that the camera scan rate could not be doubled, but the bandwidth of the video signal would have to be increased, thus increasing the electronics cost, as mentioned previously. Also, broadcasting channels were taken into account, which would have to be wider, and therefore fewer channels would be available for use, without interference, in a dedicated frequency area.

All of the above forced the engineers to use a trick, similar to the Maltese Cross used in film projection, where 50 (60) pictures would be reproduced without increasing the bandwidth. The name of this trick is ***interlaced scanning***.



Simplified representation of the interlaced scanning

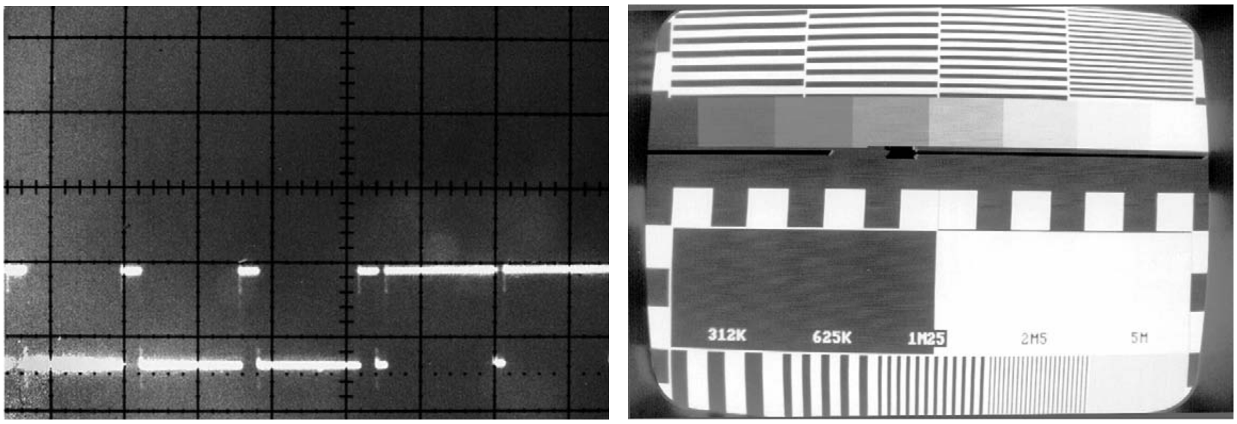
Instead of composing the pictures with 625 (525) horizontal lines by progressive scanning, the solution was found in the alternate scanning of odd and even lines. In other words, instead of a single TV picture being produced by 625 (525) lines in one progressive scan, the same **picture was broken into two halves**, where one-half was composed of only **odd lines** and the other of only **even lines**. These were scanned in such a way that they precisely fitted in between each other's lines. This is why it is called interlaced scanning. All of the lines in each half – in the case of the CCIR signal 312.5 and in NTSC 262.5 – form a so-called *TV field*. There are 25 odd fields and 25 even fields in the CCIR and SECAM systems, and 30 in the EIA system – a total of 50 fields per second, or 60 in EIA, flicking one after the other, every second.



Vertical sync area as seen on an oscilloscope

An odd field together with the following even field composes a so-called *TV frame*. Every CCIR/PAL and SECAM signal is thus composed of 25 frames per second, or 50 fields. Every EIA/NTSC signal is composed of 30 frames per second, which is equivalent to 60 fields.

The actual scanning on the monitor screen starts at the top left-hand corner with line 1 and then goes to line 3, leaving a space between 1 and 3 for line 2,



The vertical sync pulses shown on an oscilloscope (left) and on a monitor with V-Hold adjustment (right)

which is due to come when even lines start scanning. Initially, with the very first experiments, it was hard to achieve precise interlaced scanning. The electronics needed to be very stable in order to get such oscillations that the even lines fit exactly in between the odd lines. But a simple and very efficient solution was soon found in the selection of an odd number of lines, where every field would finish scanning with half a line. By preserving a linear vertical deflection (which was much easier to ensure), the half line completes the cycle in the middle of the top of the screen, thus finishing the 313th line for CCIR (263th for EIA), after which the **exact interlace was ensured for the even lines**.

When the electron beam completes the scanning of each line (on the right-hand side of the CRT, when seen from the front), it receives a ***horizontal synchronization pulse*** (commonly known as ***horizontal sync***). This sync is embedded in the video signal and comes after the line video information. It tells the beam when to stop writing the video information and to **quickly** fly back to the left at the beginning of the new line. Similarly, when a field finishes a ***vertical sync*** pulse, it "tells" the beam when to stop "writing" the video information and to **quickly** fly back to the beginning of the new field. The fly-back period of the electron beam scanning is faster than the actual active scanning, and it is only positional. That is, no electrons are ejected during these periods of the picture synthesis.



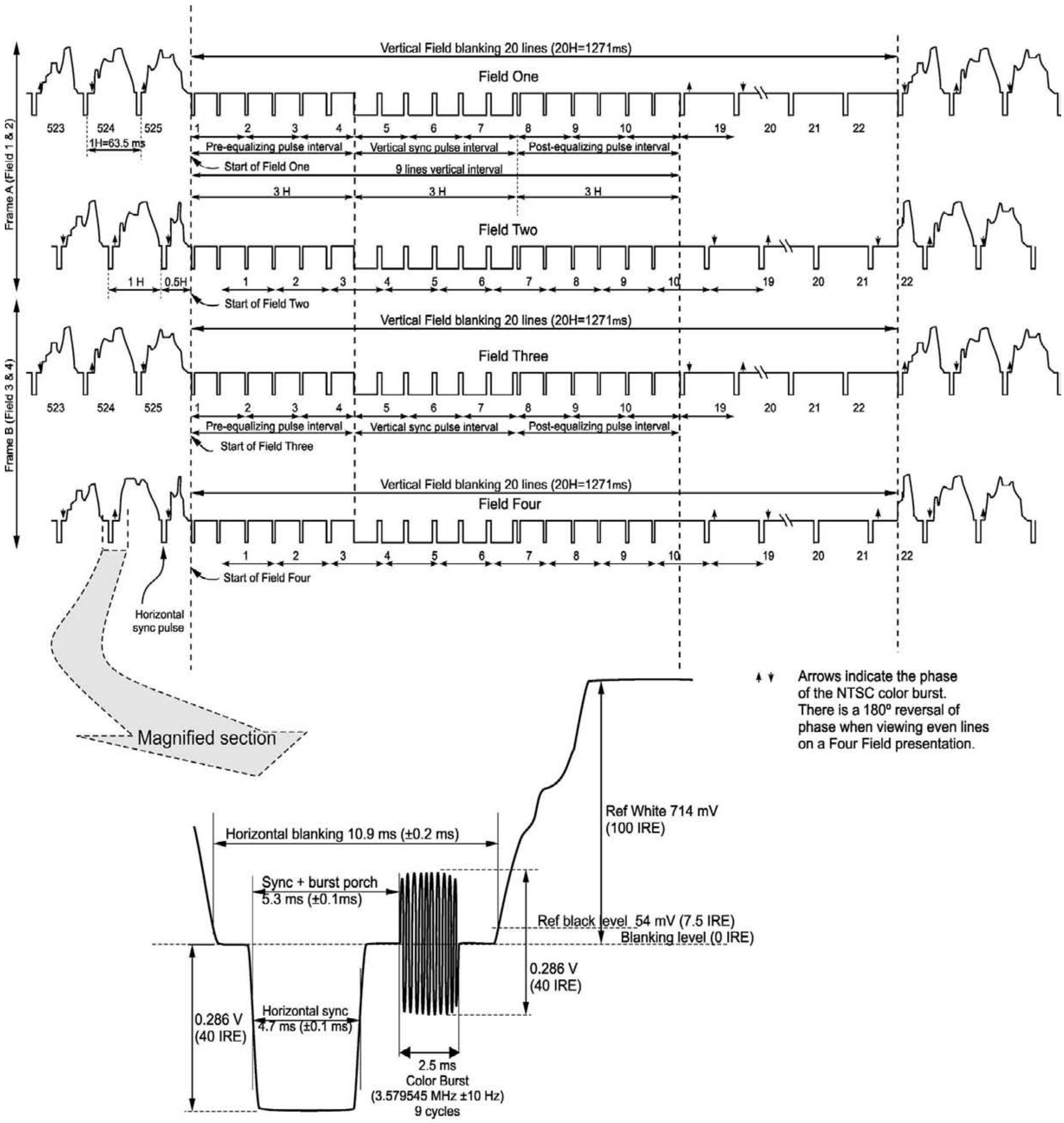
A test pattern generator signal and its waveform on an oscilloscope

In reality, even though the scanning system is called 525 TV lines (or 625 for PAL), **not all of the lines are active, that is, visible on the screen**. As can be seen on the NTSC and PAL TV Signal Timing Chart (on the next two pages), some of the lines are used for vertical sync equalization, others are not used, and still others are practically invisible because of the overscanning effect. Remember, no monitor or TV shows 100% of the camera video signal, except for the special broadcasting monitors.

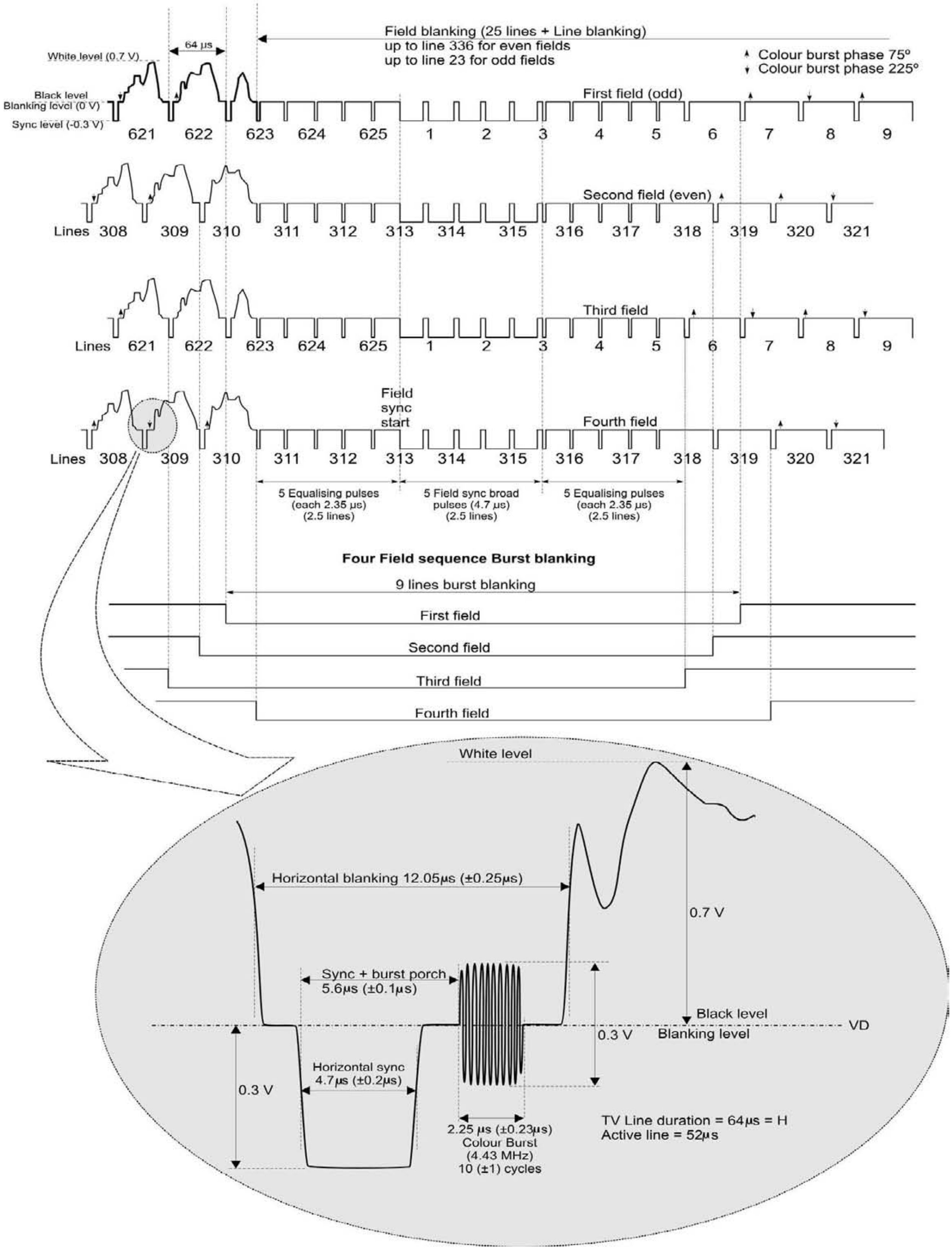
If we take into account the errors in the beam interlace, the thickness of the beam and so on in the CCIR system (and again, a similar logic applies to the other standards), we cannot count more than 576 active TV lines in PAL and not more than 480 in NTSC. These are the limits of analog PAL and NTSC television.

Timing intervals of TV signals	*NTSC (μs)*	*PAL (μs)*
Field period	*16,683*	*20,000*
Line period	*63.5*	*64*
Line blanking interval	*10.7 ~ 11.1*	*11.8 ~ 12.3*
Front porch interval	*1.4 ~ 1.6*	*1.3 ~ 1.8*
Line synchronization pulse interval	*4.6 ~ 4.8*	*4.5 ~ 4.9*
Field blanking interval	*20 H + 1 H*	*25 H + 1 H*
Duration of field synchronization pulse sequence	*3 H*	*2.5 H*
Duration of pre-equalizing pulse sequence	*3 H*	*2.5 H*
Duration of post-equalizing pulse sequence	*3 H*	*2.5 H*
Equalizing pulse interval	*2.2 ~ 2.4*	*2.2 ~ 2.4*
Interval between field synchronizing pulses	*4.6 ~ 4.8*	*4.5 ~ 4.9*
Start of color burst, from leading edge of line sync pulse	*5.2 ~ 5.4*	*5.5 ~ 5.7*
Color subcarrier burst duration (NTSC 9 cycles, PAL 10 cycles)	*2.5*	*2.0 ~ 2.5*
Duration of burst blanking pulse (per field)	*9 H*	*9 H*

NTSC television timing chart



PAL B television timing chart



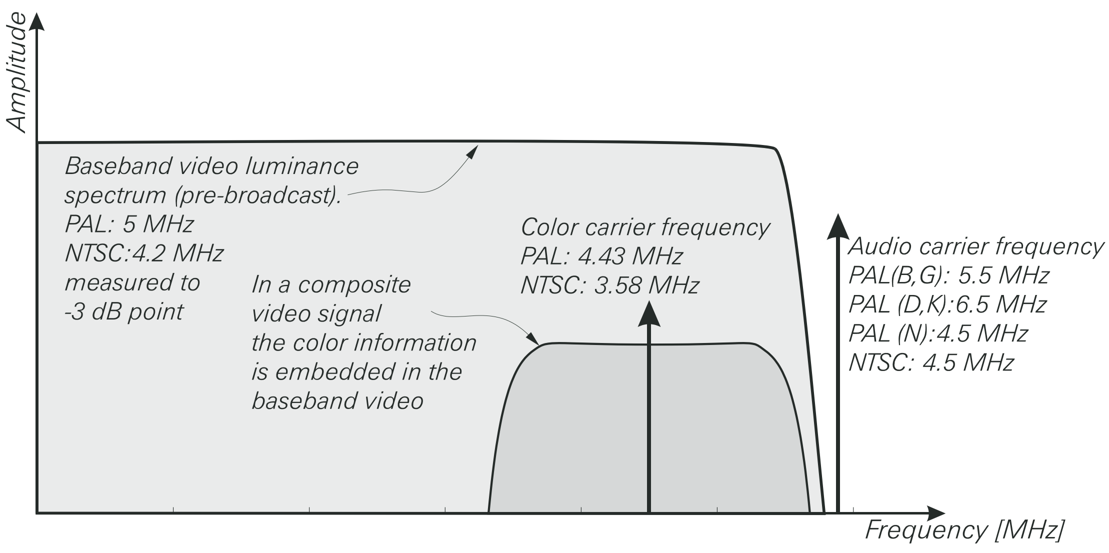
Some of the “invisible” lines are used for other purposes quite efficiently. In the PAL Teletext concept, for example, the CCIR recommends lines 17, 18, 330, and 331, where 8-bit digital information is inserted. The Teletext decoder in your TV or VCR can accumulate the fields’ digital data, which contain information about the weather, exchange rates, Lotto, and so on.

In some NTSC systems, line 21 carries closed captioning (i.e., subtitling information). Some of the other invisible lines are used for specially shaped ***video insertion test signals*** (VITS**),** which when measured at the receiving end, give valuable information on the quality of the transmission and reception in a particular area. In CCTV, some manufacturers use the invisible lines to insert camera ID, time and date, or similar information. When recorded on a VCR, these lines are also recorded but they are not visible on the monitor screen. However, the information is always there, embedded in the video signal. This type of information is more secure and harder to tamper with. It can be retrieved with a special TV line decoder and used whenever necessary, revealing the camera ID together with the time and date of the particular signal and, for example, the intruder in the picture.

The video signal and its spectrum

This heading discusses the theoretical fundamentals of the video signal’s limitations, bandwidth, and resolution. This is a complex subject with its fundamentals involving higher mathematics and electronics, but I will try to explain it in plain and simple language.

Most of the artificial electrical signals can be described mathematically. Mathematical description is very simple for signals that are periodical, like the main power, for example. A periodical function can always be represented with a sum of sine waves, each of which may have different amplitude and phase. Similar to a spectrum of white light, this is called ***spectrum of an electrical signal***. The more periodical the electrical signal is, the easier it can be represented and with fewer sine wave components. Each sine wave component can be represented with discrete value in the frequency spectrum of the signal. The less periodical the function is, the more components will be required to reproduce the signal. Theoretically,

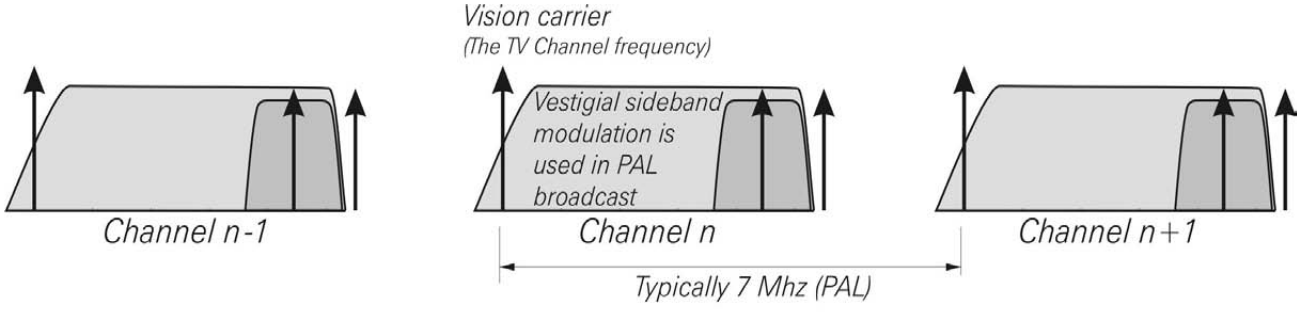


The spectrum of a baseband composite video signal

even a nonperiodical function can be represented with a sum of various sine waves, only that in such a case there will be a lot more sine waves to summarize in order to get the nonperiodical result. In other words, the spectral image of a nonperiodical signal will have a bandwidth more densely populated with various components. The finer the details the signal has, the higher the frequencies will be in the spectrum of the signal. Very fine details in the video signal will be represented with high-frequency sine waves. This is equivalent to high-resolution information. A signal rich with high frequencies will have wider bandwidth. Even a single, but very sharp, pulse will have a very wide bandwidth.

The above describes, in a very simplified way, the very important ***Fourier spectral theory***, which states that **every signal in the time domain has its image in the frequency domain**. The Fourier spectral theory can be used in practice – wide bandwidth periodical electrical signals can be more efficiently explored by analyzing their frequency spectrum. Without going deeper into the theory itself, CCTV users need to accept the concept of the spectrum analysis as very important for examining complex signals, such as the video itself. The video signal is perhaps one of the most complex electrical signals ever produced, and its precise mathematical description is almost impossible because of the constant change of the signal in the time domain. The video information (that is, luminance and chrominance components) changes all the time. Because, however, we are composing video images by **periodical** beam scanning, we can **approximate** the video signal with some form of a periodical signal. One of the major components in this periodicity will be the line frequency – for CCIR and SECAM, 25 × 625 = 15,625 Hz; for EIA, 30 × 525 = 15,750 Hz.

It can be shown that the spectrum of a simplified video signal is composed of ***harmonics*** (multiples) of the line frequency around which there are companion components, both on the left- and right-hand sides (***sidebands***). The intercomponent distances depend on the contents of the video picture and the dynamics of the motion activity. Also, it is very important to note that such a spectrum, composed of harmonics and its components, is **convergent,** which means the harmonics become smaller in amplitude as the frequency increases. One even more important conclusion from the Fourier spectral theory is that **positions of the harmonics and components in the video signal spectrum depend only on the picture analysis** (4:3 ratio, 625 interlaced scanning). The video signal energy distribution around the harmonics depends on the contents of the picture. The harmonics, however, are **at exact positions because they only depend on the line frequency**. In other words, the video signal dynamics and amplitude of certain components in the sidebands will vary, but the harmonics locations (as subcarrier frequencies) will remain constant.



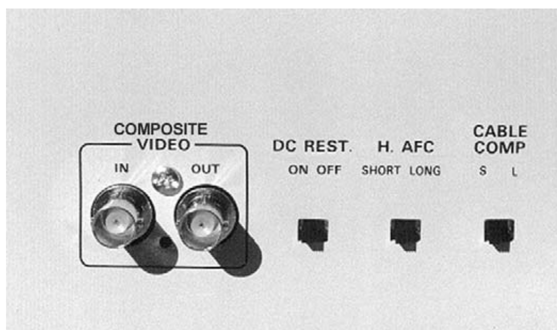
Broadcast TV channels frequency displacement example (PAL)

This is a very important conclusion. It helped find a way, in broadcast TV, to reduce the spectrum of a video signal to the minimum required bandwidth without losing too many details. There is always a compromise, of course, but since **the majority of the video signal energy is around the zero frequency and the first few harmonics, there is no need and no way to transmit the whole video spectrum**. Scientists and engineers have used all of these facts to find a compromise, to find how little of the video bandwidth need be used in a transmission, without losing too many details. As we already mentioned when discussing different TV standards, the more scanning lines that are used in a system the wider the bandwidth will be, and the higher the resolution of the signal is the wider the bandwidth will be.

Taking into account the electron beam's limited size (which also dictates the smallest reproducible picture elements), the physical size of the TV screens, viewing distances, and the complexity and production costs of domestic TV sets, it has been concluded that for a good reproduction of a broadcast signal, 5 MHz of video bandwidth is sufficient. **Using a wider bandwidth is possible, but the quality gain factor versus the expense is very low**. As a matter of fact, in the broadcast studios, cameras and recording and monitoring equipment are of much higher standards, with spectrums of up to 10 MHz. This is for internal use only, however, for quality recording and dubbing. Before such a signal is RF modulated and sent to the transmitting stage, it is cut down to 5 MHz video, to which about 0.5 MHz is added for the left and right audio channels. When such a signal comes to the TV transmitter stage it is modulated so as to have only its vestigial side band transmitted, with a total bandwidth, including the separation buffer zone, of 7 MHz (for PAL). But please note that the actual usable video bandwidth in broadcast reception is only 5 MHz. For the more curious readers we should mention that in most PAL countries, the video signal is modulated with amplitude modulation (AM) techniques, while the sound is frequency modulated (FM).

Similar considerations apply when considering NTSC signals, where the broadcasted bandwidth is around 4.2 MHz.

In CCTV, with the majority of system designs, **we do not have such bandwidth limitations** because we do not transmit an RF-modulated video signal. We do not have to worry about interference between neighboring video channels. In CCTV, we use a raw video signal as it comes out of the camera, which is a **basic bandwidth video,** or usually called ***baseband video***. This usually bears the abbreviation ***CVBS***, which stands for composite video burst signal. The spectrum of such a signal, as already mentioned, ranges from 0 to 10 MHz, depending on the source quality.



Bayonet Neill-Concelman (BNC) is the most common composite video input connector in CCTV.

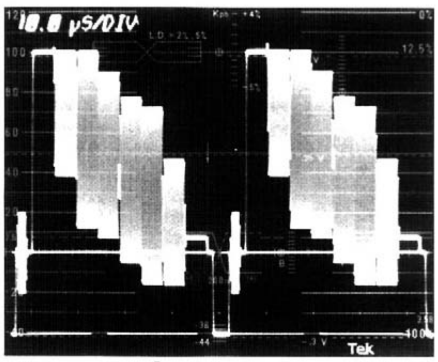
The spectral capacity of the coaxial cable, as a transmission medium, is much wider than this. The most commonly used 75Ω coaxial cable RG-59B/U, for example, can easily transmit signals of up to 100 MHz bandwidth. This is applicable to a limited distance of a couple of hundred meters of course, but that is sufficient for the majority of CCTV systems. Different transmission media imply different bandwidth limitations, some of which are wider and some narrower than the coaxial one, but most of them are considerably wider than 10 MHz.

Color video signal

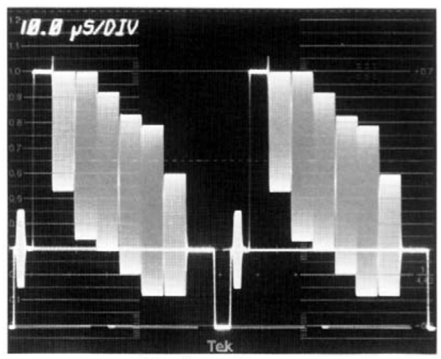
When color television was introduced, it was based on monochrome signal definitions and limitations. Preserving the compatibility between B/W and color TV was of primary importance. The only way color information (chroma) could be sent together with the luminance without increasing the bandwidth was if the color information was modulated with a frequency that fell exactly in between the luminance spectrum components. This means that the spectrum of the chrominance signal is interleaved with the spectrum of the luminance signal in such a way that they do not interfere. This color frequency is called a ***chroma subcarrier*** and the most suitable frequency, for **PAL**, was found to be **4.43361875 MHz**. In **NTSC**, using the same principle, the color subcarrier was found to be **3.579545 MHz**.

At this point we need to be more exact and highlight that NTSC is defined with 29.97 frames exactly, not 30 (!). The reason for this is the definition of color signal in NTSC, as proposed by the RS170A video standard, which is based on the exact subcarrier frequency of 3.579545 MHz. The horizontal scanning frequency is defined as 2/455 times the burst frequency, which makes 15,734 Hz. The vertical scanning frequency is derived from this one, and the NTSC recommends it as 2/525 times the horizontal frequency. This produces 59.94 Hz for the vertical frequency (i.e., the field rate). For the purpose of generalization and simplification, however, we will usually refer to NTSC as a 60-field signal in this book.

The basics of color composition in television lie in the additive mixing of three primary color signals: red, green, and blue. So, for transmitting a complete color signal, theoretically, apart from the luminance information, another three different signals are required. Initially, in the beginning of the color evolution, this seemed impossible, especially when only between 4 and 5 MHz are used to preserve the compatibility with the B/W standards.

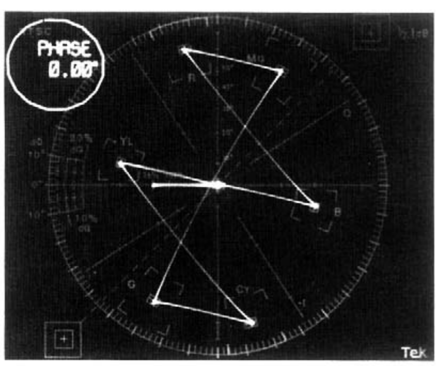


Color bars

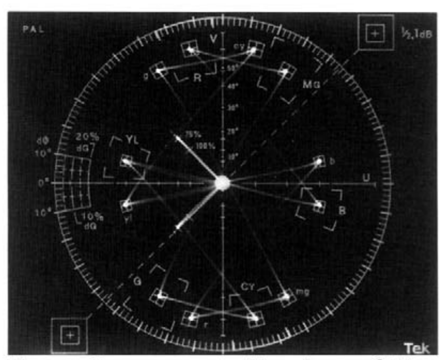


Color bars

With a complex but clever procedure, this was made possible. It is beyond the scope of this book to explain such a procedure, but the following facts are important for our overall understanding of the complexity of color reproduction in television.



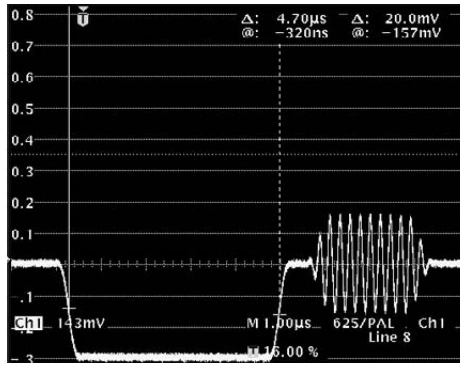
A vectorscope display of the color bars above (NTSC)



A vectorscope display of the color bars above (PAL)

In a real situation, apart from the ***luminance*** signal,

which is often marked as $Y = U_Y$, **two more signals** (not three) are combined. These signals are the so-called ***color differences*** $V = U_R - U_Y$, and $U = U_B - U_Y$, which means the difference between the red and the luminance signal and between the blue and the luminance. Color differences are used instead of just plain values for R, B (and G) because of the compatibility with the B/W system. Namely, it was found that when a white or gray color is transmitted through the color system, only a luminance signal needs to be present in the CRT. In order to eliminate the color components in the system, the color difference was introduced.



Color burst waveform

Having in mind the basic relationship among the three color signals:

$$U_Y = 0.3U_R + 0.59U_G + 0.11U_B \qquad (36)$$

we can show that **all three primary color signals can be retrieved using the luminance and color difference signals**:

$$U_R = (U_R - U_Y) + U_Y \qquad (37)$$

$$U_B = (U_B - U_Y) + U_Y \qquad (38)$$

$$U_G = (U_G - U_Y) + U_Y \qquad (39)$$

For white color $U_R = U_G = U_B$, thus $U_Y = (0.3 + 0.59 + 0.11)U_R = U_B = U_G$. The green color difference is not transmitted, but it is obtained from the following calculation (again using (36)):

$$U_G - U_Y = -0.51(U_R - U_Y) - 0.19(U_B - U_Y) \qquad (40)$$

This relation shows that in color television, apart from the luminance, only **two additional** signals would be sufficient for successful color retrieval. That is the red and the blue color difference (*V* and *U*), and they are embedded in the CVBS signal.

Because the R, G, and B components are derived from the color difference signals by way of simple and linear matrix equations, which in electronics can be realized by simple resistor networks, these arrangements are called ***color matrices***.

It should be noted here that the two discussed TV standards, NTSC and PAL, base their theory of color reproduction on two different exponents of the CRT phosphor (called ***gamma***, which will be explained in Chapter 6). The NTSC assumes a gamma of 2.2, and PAL 2.8. This assumption is embedded in the signal encoding prior to transmission.

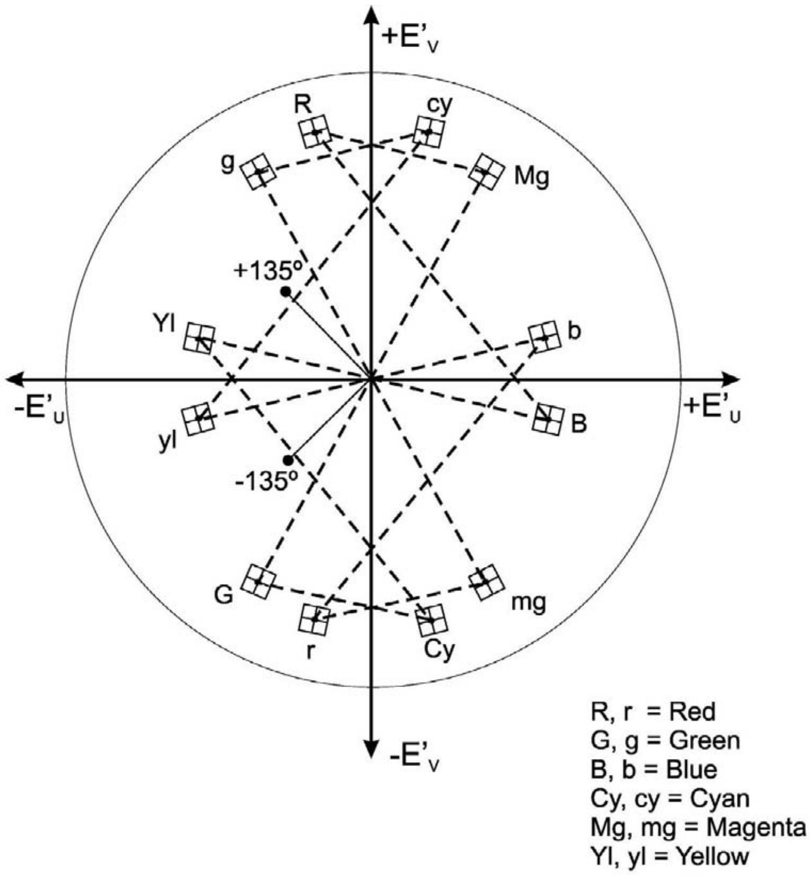
In practice, gamma of 2.8 is a more realistic value, which is also reflected in a higher contrast picture. Of course, the reproduced color contrast will depend on the monitor's phosphor gamma itself.

In order to combine (modulate) these color difference signals with the luminance signal for

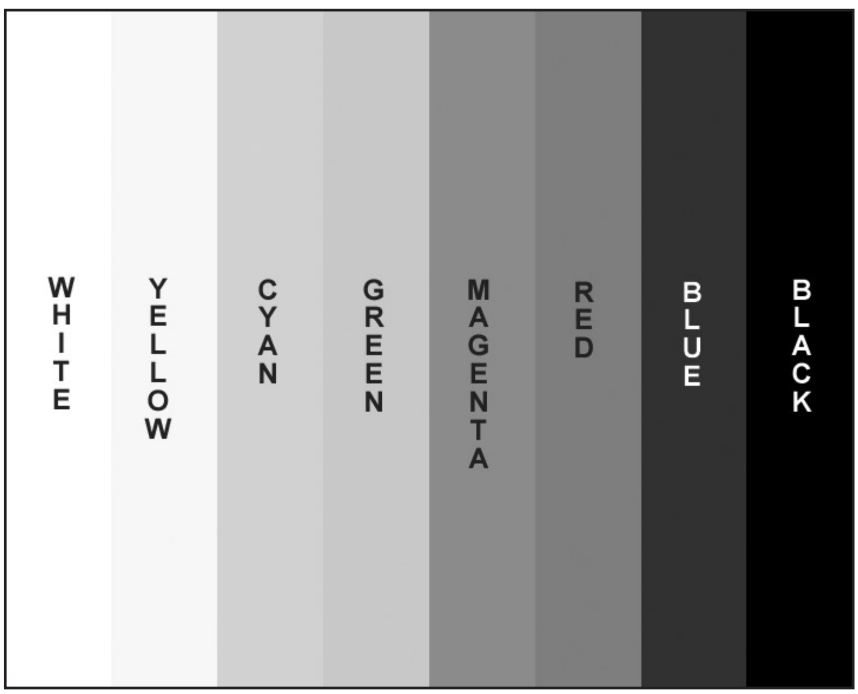
broadcast transmission, a so-called ***quadrature amplitude modulation*** is used where the two different signals (V and U) modulate a single-carrier frequency (color subcarrier). This is possible by introducing a phase difference of 90° between the two, which is the reason for the name ***quadrature modulation***.

In the PAL color standard, we have another clever design to minimize the color signal distortions. Knowing that **the human eye is more sensitive to color distortions than to changes in brightness**, a special procedure was proposed for the color encoding so that distortions would be minimized, or at least made less visible. This is achieved by the color phase change, of 180°, in every second line.

So, if transmission distortions occur, which is usually in the form of phase shifting, they will result in a color change of the same amount. But because **the electronic vector representation of colors is chosen so that complementary colors are opposite each other, the errors are also complementary and, when "errored" lines next to each other are seen from a viewing distance, the errors will cancel each other out**. This is the reason for the name phase alternating line (PAL).



PAL color vectors

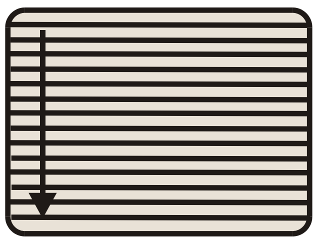


Standard order of color bars in television

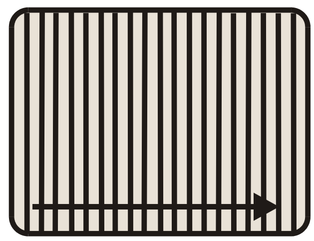
Resolution

Resolution is the property of a system to display fine details. The higher the resolution, the more details we can see. The resolution of a TV picture depends on the number of active scanning lines, the quality of the camera, the quality of the monitor, and the quality of the transmitting media.

Since we use two-dimensional display units (CCD chips and CRTs), we distinguish two kinds of resolutions: vertical and horizontal.



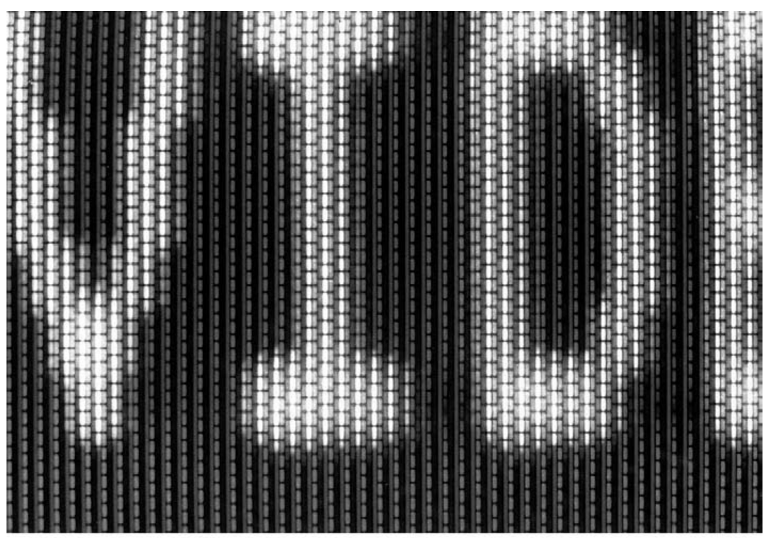
Vertical resolution



Horizontal resolution

The vertical resolution is defined by the number of vertical elements that can be captured on a camera and reproduced on a monitor screen. When many identical vertical elements are put together in the scanning direction, we get very dense horizontal lines. This is why we say **the vertical resolution tells us how many horizontal lines we can distinguish**. Both black and white lines are counted, and the counting is done vertically. Clearly, this is limited by the number of scanning lines used in the system – we cannot count more than 625 lines in a CCIR system or 525 in an EIA system. If we take into account the duration of the vertical sync and the equalization pulses, the invisible lines, and so on, **the number of active lines in CCIR comes down to 576 lines and about 480 in EIA.**

This is still not the actual vertical resolution. Usually, the resolution is measured with a certain patterned image in front of the camera, so there are a lot of other factors to take into account. One is that the absolute position of the supposedly high-resolution horizontal pattern can never exactly match the interlaced lines pattern. Also, the monitor screen overscanning cuts a little portion of the video picture, the thickness of the electronic beam is limited, and for color reproduction the "grill mask" is limited.



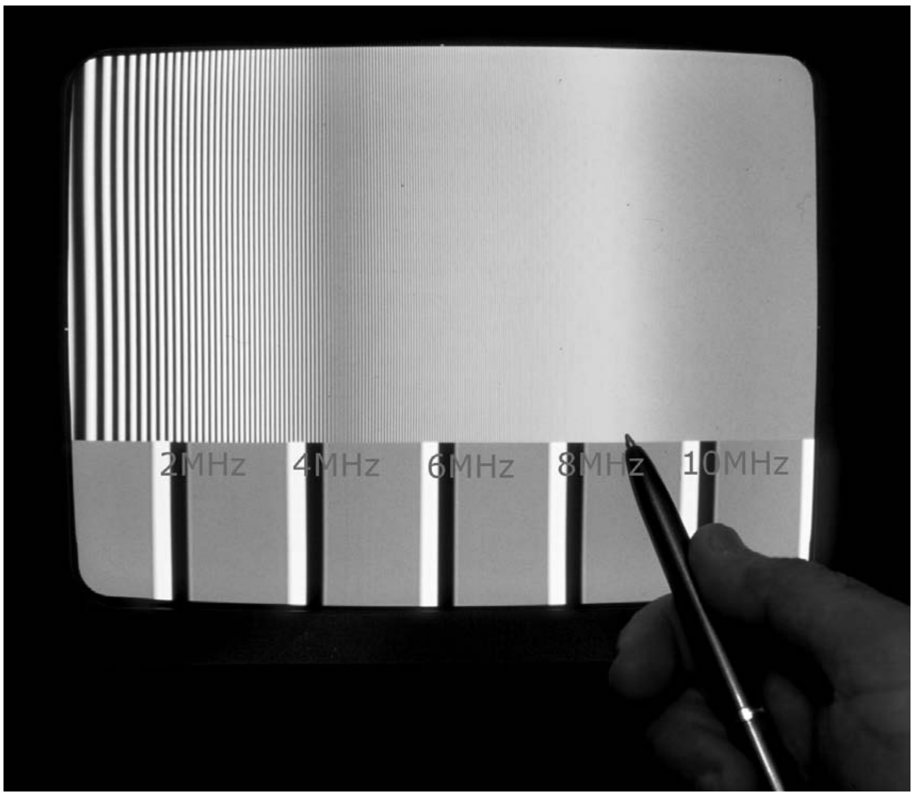
Close-up of a color screen

As early as 1933, Ray Kell and his colleagues found by experimenting that a **correction factor** of 0.7 should be applied when calculating the "real" vertical resolution. This is known as the ***Kell Factor***, and it is accepted as a pretty

good approximation of the real resolution. This means that 576 has to be corrected (multiplied) by 0.7 to get the **practical limits** of the vertical resolution for PAL, which is approximately 400 TV lines. The same calculation applies for the NTSC signal, which will give us approximately 330 TV lines of vertical resolution. This is all true in an ideal case, that is, with excellent video signal transmission.

Horizontal resolution is a little bit of a different story. **The horizontal resolution is defined by the number of horizontal elements that can be captured by a camera and reproduced on a monitor screen**. And, similar to what we said about the vertical resolution, **the horizontal tells us how many vertical lines can be counted.**

One thing is different, however, because of the TV aspect ratio of 4:3, the width is greater than the height. So, to preserve the natural proportions of the images, **we count only the vertical lines of the width equivalent to the height** (i.e., three-quarters of the width). This is why we do not refer to the horizontal resolution as just lines but rather ***TV lines***.



A 12 MHz sweep generator is used to check the bandwidth of a high-resolution monitor (shown 9 MHz = 700 TVL).

The horizontal resolution of a monochrome (B/W) TV system is theoretically only limited to the cross section of the electron beam, the monitor electronics, and, naturally, the camera specifications. In reality, there are a lot of other limitations. One is the video bandwidth applicable to the type of transmission. Even though we may have high-resolution cameras in the TV studio, we transmit only 5 MHz of the video spectrum (as discussed earlier); therefore there is no need for television manufacturers to produce TV receivers with a wider bandwidth. In CCTV, however, the video signal bandwidth is dictated mostly by the camera itself, since B/W monitors have a very high resolution (up to 1000 TV lines), which is limited only by the monitor quality, of which the most important are the electron beam precision and cross section.

A color system has an additional barrier, and that is the physical size of the color mask and its pitch. The color mask is in the form of a very fine grille. This grille is used for the color scanning with the three primary colors, red, green, and blue. The number of the grille's color picture elements (RGB dots) is determined by the size of the monitor screen and the quality of the CRT. In CCTV, anything from 330

TV lines (horizontal resolution) up to 600 TV lines is available. The most common are the standard 14 monitors with around 400 TV lines of resolution. Remember, we are talking about TV lines, which in the horizontal direction gives us an absolute maximum number of 400 × 4/3 = 533 vertical lines.

In CCTV, as in broadcast TV, we cannot change the vertical resolution since we are limited to the number defined by the scanning system. That is why we rarely argue about vertical resolution. **The commonly accepted number for realistic vertical resolution is around 400 TV lines for CCIR and 330 TV lines for EIA**. The horizontal resolution we can change; this will depend on the camera's horizontal resolution, the quality of the transmission media, and the monitor. It is not rare in CCTV to come across a camera with 570 TV lines of horizontal resolution, which corresponds to a maximum of approximately 570 × 4/3 = 760 lines across the screen. This type of camera is considered a high-resolution camera. A standard resolution B/W camera would have 400 TV lines of horizontal resolution.

There is a simple relation between the bandwidth of a video signal and the corresponding number of lines. If we take one line of a video signal, of which the active duration is 57 μs, and spread 80 TV lines across it, we will get a total of 80 × 4/3 = 107 lines. These lines, when represented as an electrical signal, will look like sine waves. So, a pair of black and white lines actually corresponds to one period of a sine wave. Therefore, 107 lines are approximately 54 sine waves. A sine wave period would be 57 μs/54 = 1.04 μs. If we apply the known relation for time and frequency (i.e., $T = 1/f$), we get $f = 1$ MHz. The following is a very simple rule of thumb, giving us the relation between the bandwidth of a signal and its resolution: **approximately 80 TV lines correspond to 1 MHz in bandwidth.**

Instruments commonly used in TV

It is very hard to determine any of the video signal properties with a typical electronic multimeter. There are, however, specialized instruments that, when used correctly, can describe the tested video signal precisely. These instruments include ***oscilloscopes***, ***spectrum analyzers***, and ***vectorscopes***. In most cases an oscilloscope will be sufficient, and I strongly recommend that the serious technician or engineer invest in it.

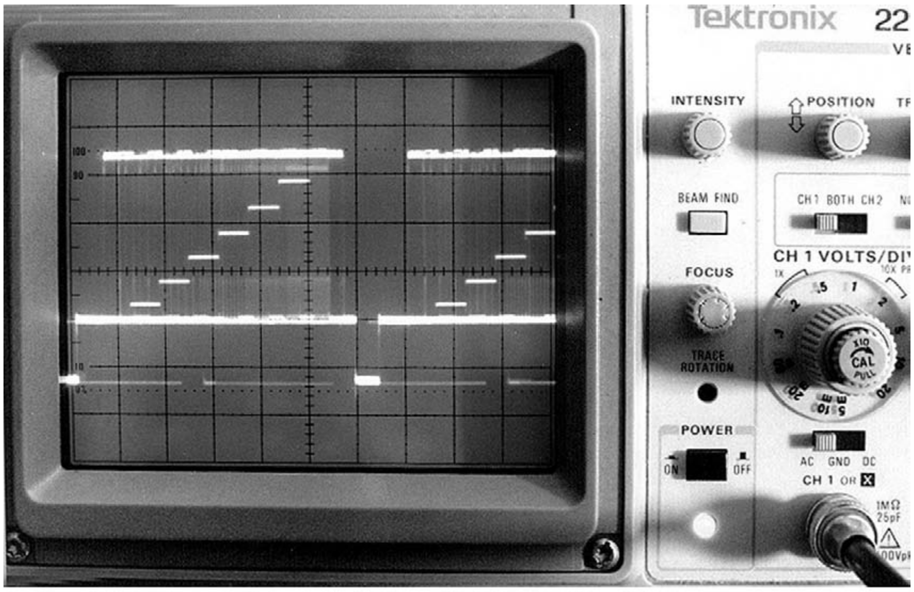
Oscilloscope

The change of a signal (timewise) can be slow or fast. What is slow and what is fast depends on many things, and they are relative terms. One periodical change of something in one second is defined as Hertz. Audio frequency of 10 kHz makes 10,000 oscillations in one second. The human ear can hear a range of frequencies from around 20 Hz up to 15,000–16,000 Hz. A video signal, as defined by the aforementioned standards, can have frequencies from nearly 0 Hz up to 5–10 MHz.

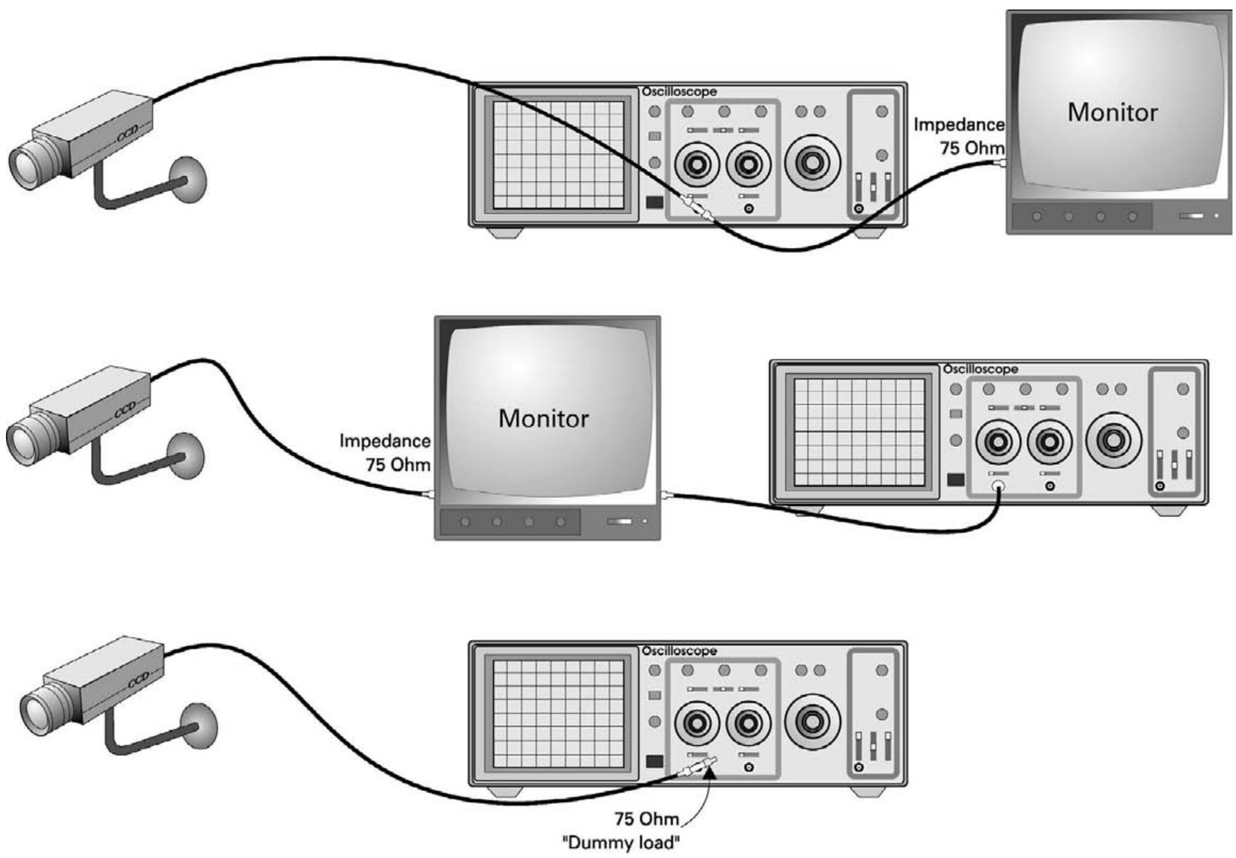
The higher the frequency, the finer the detail in the video signal.

How high we can go depends, first of all, on the pickup device (camera) but also on the transmission (coaxial cable, microwave, fiber optics), and the processing/displaying media (VCR, framestore, hard disk, monitor).

A time analysis of any electrical signal (as opposed to a frequency analysis) can be conducted with an electronic instrument called an ***oscilloscope***. The oscilloscope works on principles similar to those of a TV monitor; only in this case the scanning of the electron beam follows the video signal voltage in the vertical direction, while horizontally, time is the only variable. With the so-called time-base adjustment, video signals can be analyzed from a frame mode (20 ms) down to the horizontal sync width (5 μs).



An oscilloscope



A few different methods of correct measurement with an oscilloscope

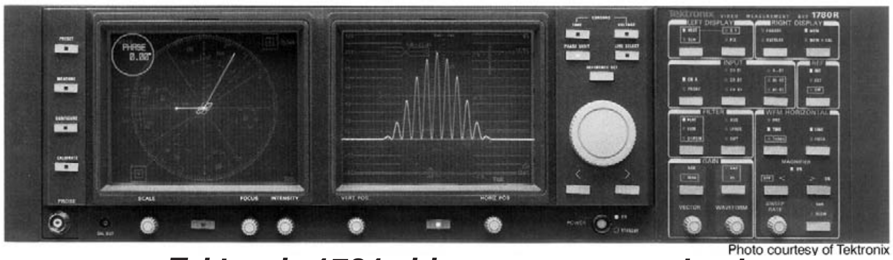


Photo courtesy of Tektronix

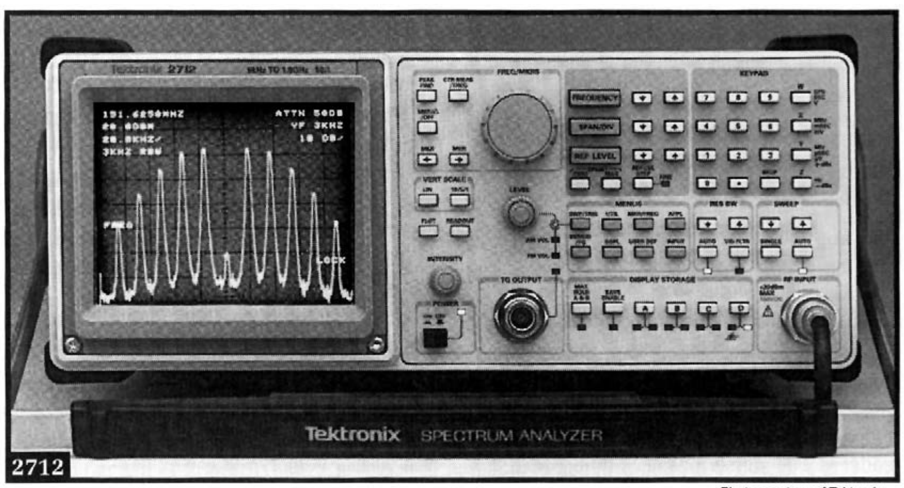
Tektronix 1781 video measurement set

Oscilloscope measurements have the most objective indication of the video signal quality, and it is strongly recommended to anyone seriously involved in CCTV. First, with an oscilloscope it is very easy to see the quality of the signal, bypassing any possible misalignment of the brightness/contrast on a monitor. Sync/video levels can easily be checked and can confirm whether a video signal has a proper 75-Ω termination, how far the signal is (reduction of the signal amplitude and loss of the high frequencies), and whether there is a hum induced in a particular cable. Correct termination is always required for proper measurements. That is, the input impedance of an oscilloscope is high and whichever way the signal is connected, it needs to see 75 Ω at the end of the line. A few examples of how an oscilloscope is to be connected for the purposes of correct video measurement are shown on the diagram on the previous page.

Spectrum analyzer

Every electrical signal that changes (timewise) has an image in the frequency domain, as already discussed by the Fourier theory. The frequency domain describes the signal amplitude versus frequency instead of versus time. The representation in the frequency domain gives us a better understanding of the composition of an electrical signal. The majority of the contents of the video signal are in the low to medium frequencies, while fine details are contained in the higher frequencies. An instrument that shows such a spectral composition of signals is called a ***spectrum analyzer***.

A spectrum analyzer is an expensive device and is not really necessary in CCTV. However, if used properly, when combined with a test pattern generator with a known spectral radiation, a lot of valuable data can be gathered. Video signal attenuation, proper cable equalization, signal quality, and so on can be precisely determined. In broadcast TV, the spectrum analyzer is a must for making sure that the broadcast signal falls within certain predefined standard margins.

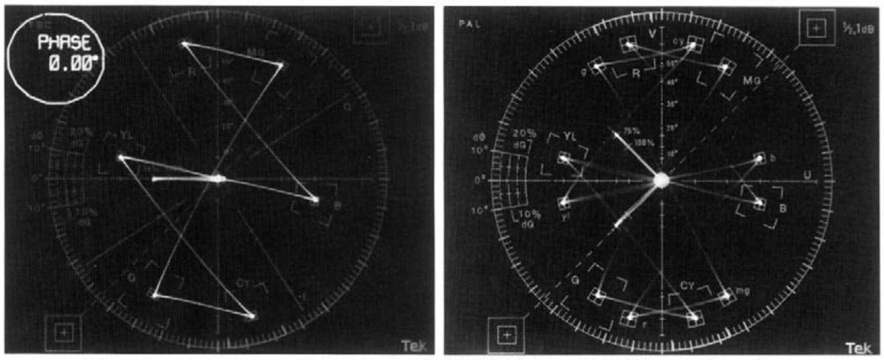


A spectrum analyzer

Photo courtesy of Tektronix

Vectorscope

For measuring the color characteristics of a video signal an instrument called a ***vectorscope*** is used. A vectorscope is a variation of an oscilloscope, where the signal's color phase is shown. The display of a vectorscope is in the polar form, where primary colors have exact known positions with angles and radii. The vectorscope is rarely used in CCTV but could be necessary when specific colors and lighting conditions need to be reproduced.



Vectorscope display of NTSC and PAL color bars

In most cases, a color CCD camera will have an automatic white balance that, as discussed earlier in the color temperature section, compensates for various color temperature light sources. Sometimes, however, with manual white balance cameras, a color test chart may need to be used, and with the help of a vectorscope, colors can be fine-tuned to fall within certain margins, marked on the screen as little square windows. It should be noted that a vectorscope display of the same image in NTSC is different from the vectorscope display in PAL, and this is because of the difference of color encoding in the two systems. PAL has vertically symmetrical color vectors, as it can be seen in the photos above.

Many other practical instruments (designed for the broadcast industry really) can be used in CCTV. With a little bit of understanding and willingness to learn, many features of a video component, or a whole system, can be quantified. Some instruments combine more measuring devices into one box.

If you are serious about CCTV, these should be considered valuable tools of your trade.

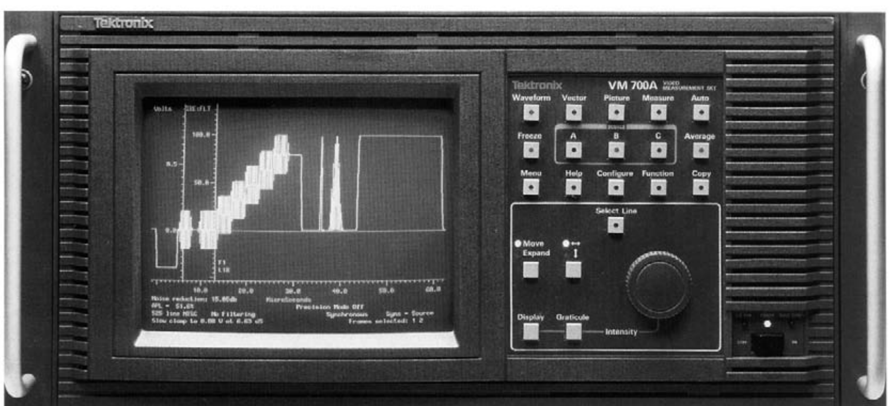


Photo courtesv of Tektronix

Tektronix VM700 video measurement set

Television systems around the world

There are a number of variations of the three major systems PAL, NTSC, and SECAM. Various countries have accepted various broadcast bandwidths, color subcarrier frequencies, and sound carriers. These variations are usually referred to with a suffix next to the system a country uses.

The following tables show variations of the three major systems, and at the end of this chapter we list most of the countries of the world with their respective standards.

With many newly designed TV sets and VCRs there is no need to know what standard you have as the set will automatically find the standard, but as technical people it is a good idea to know what is in use.

With the new digital standards, hopefully, there will be much less variation around the world.

SYSTEM	PAL B,G,H	PAL I	PAL D	PAL N	PAL M
Line/Field	625/50	625/50	625/50	625/50	525/60
Horizontal Frequency	15.625 kHz	15.625 kHz	15.625 kHz	15.625 kHz	15.750 kHz
Vertical Frequency	50 Hz	50 Hz	50 Hz	50 Hz	60 Hz
Color Sub Carrier Frequency	4.433618 MHz	4.433618 MHz	4.433618 MHz	3.582056 MHz	3.575611 MHz
Video Bandwidth	5.0 MHz	5.5 MHz	6.0 MHz	4.2 MHz	4.2 MHz
Sound Carrier	5.5 MHz	6.0 MHz	6.5 MHz	4.5 MHz	4.5 MHz

SYSTEM	NTSC M
Lines/Field	525/60
Horizontal Frequency	15.734 kHz
Vertical Frequency	60 Hz
Color Subcarrier Frequency	3.579545 MHz
Video Bandwidth	4.2 MHz
Sound Carrier	4.5 MHz

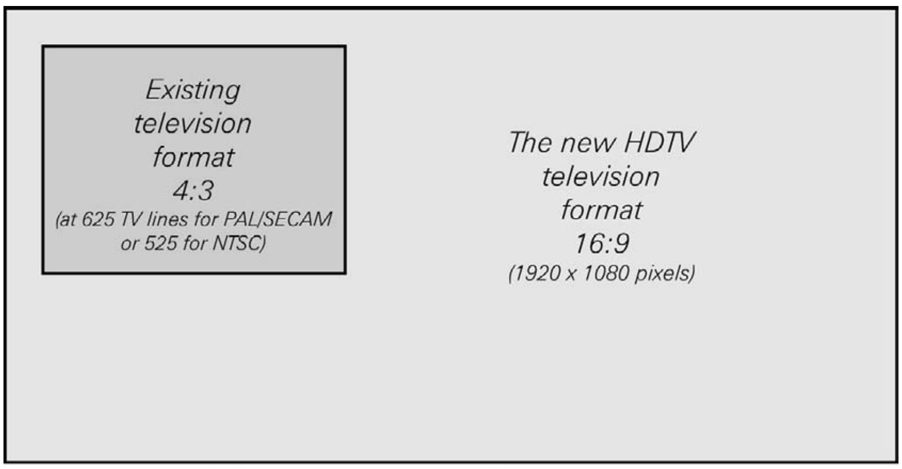
SYSTEM	SECAM B,G,H	SECAM D,K,K1,L
Line/Field	625/50	625/50
Horizontal Frequency	15.625 kHz	15.625 kHz
Vertical Frequency	50 Hz	50 Hz
Video Bandwidth	5.0 MHz	6.0 MHz
Sound Carrier	5.5 MHz	6.5 MHz

HDTV

High-definition television (HDTV) has arrived. Many experiments and tests have been conducted, and most importantly, the technology has now been developed to a stage where it can be mass produced. Many countries have already started broadcasting HDTV and are slowly phasing out the old analog TV. This is supposed to happen by the end of 2006 in the United States, and by the end of 2008 in Australia. All terrestrial broadcasts will be in digital format, which will be a mix of standard definition (SDTV) and HDTV.

Hopefully, it will not take too long for CCTV to follow suit.

The idea of high definition is to have approximately twice as much resolution (horizontal and vertical, which produces four times more details) and a new aspect ratio of 16:9 as opposed to the existing 4:3. The reason for this widening of the TV screen is compatibility with the majority of movie formats. By having such a resolution, HDTV offers picture quality close to 35 mm film and a sound quality equal to that of a compact disc.



HDTV and analog SDTV comparison

HDTV has been worked on for over two decades now, and the first test broadcasts have been conducted in Japan, Europe, and the United States.

In 1993 a group of institutions and companies was formed in order to evaluate the present technologies and decide on key elements that will be at the heart of the best HDTV system. This group was called The Grand Alliance, and some of its members include AT&T™, General Instrument Corporation™, Massachusetts Institute of Technology (MIT), Philips™, David Sarnoff Research Centre™, Thomson™, and Zenith™.

In 1995, the Alliance agreed to use the MPEG-2 video, audio, and system multiplexing, which is the same format as in DVD.

Two display modes have been proposed: interlaced and progressive (or noninterlaced) scanning.

The HDTV is now one of the many digital television (DTV) standards, offering the best picture

quality. There are around 18 DTV formats, of which six are HDTV formats. Five of these are based on progressive scanning and one is based on interlaced scanning.

Of the remaining formats, eight are SDTV (four wide-screen formats with 16:9 aspect ratios, and four conventional formats with 4:3 aspect ratios), and the remaining four are video graphics array (VGA) formats. Stations are free to choose which formats to broadcast.

The following formats are used in HDTV:

- 720i – 1280 × 720 pixels interlaced
- 720p – 1280 × 720 pixels progressive
- 1080i – 1920 × 1080 pixels interlaced
- 1080p – 1920 × 1080 pixels progressive

"Interlaced" or "progressive" refers to the scanning system. The interlaced is the same type of scanning as we have it in the analog CCTV, as explained previously. With modern larger and brighter television sets, the persistence of the human eye becomes a problem as it starts to pick up the flicker.

Progressive scanning shows the whole picture, and every line is produced one after another, making full pictures 50 or 60 times a second (depending on the frequency region). This provides for a much smoother picture but uses slightly more bandwidth.

The recommended viewing distances for HDTV are four times the TV height (4H), which allows for a proper cinematic experience.

The video compression algorithm in HDTV is the MPEG-2, while the audio compression is AC-3. The transmission modulation technique proposed is to be a quadrature amplitude modulation with vestigial sideband. The selected audio technology is an eight-channel, CD-quality, digital surround-sound system, using one of Dolby's cinema surround-sound techniques.

Digital terrestrial transmission broadcast (DTTB) brings to an end the direct relationship between one television program and one frequency. DTTB is capable of carrying either one HDTV program or up to six services using standard definition television (SDTV), or as many as 10 services with lower definition formatting. As with computer technology, it is possible to trade off the bit rate, the channel width, and picture quality.

Essentially, the type of picture determines how much of the channel's capacity is needed for transmission. A digital terrestrial broadcast channel can carry up to 20 Mb/s of data. HDTV services would use most, if not all, of this capacity, but an SDTV service would use considerably less depending on the nature of the service. Fast-moving sports, for example, could require up to a 10 Mb/s data rate, and hence possibly only two of these services could be delivered at one time. By comparison, a talking-head picture would utilize about 5 Mb/s of data.

DTTB systems can accommodate 6, 7, and 8 MHz channel spacings with minimal or no apparent cost disadvantage. Australia uses 7 MHz channel spacing for analog services, the United States uses 6 MHz and Europe commonly uses 8 MHz, although there is also some 7 MHz use.

DTTB can be accommodated within the existing broadcasting frequency bands, generally in UHF but also in VHF bands, using vacant channels adjacent to analog services.

These channels often cannot be used for additional analog services because of technical constraints inherent in analog systems, but they can be used for DTTB as such receivers are expected to tolerate higher levels of co-channel and adjacent channel interference.

The HDTV will naturally be more exciting to watch, and the clarity and resolution of the images will allow for much bigger screens. Initially, if such screens are based on CRT technology with which high resolution can be achieved, we cannot expect a diagonal size larger than 1 m. But with one of the new display technologies, such as the plasma display, the FED or DMD, and not excluding the LCD (all of which are discussed in Chapter 6), we will certainly see larger screen sizes, most probably only limited by the room size and the viewing distance.

For CCTV, the HDTV size will not be so critical and CRT high-definition monitors are okay since the majority of security operators and users watch the screens from a very close distance. But this is not to say that new control room designs will not take a different approach where one or two large monitors at a room’s distance will be the main control displays.

COUNTRY	COLOR SYSTEM	VHF	UHF	MAINS ELECTRICITY
AFGHANISTAN	PAL/SECAM(H)	B	-	220 50Hz
ALASKA	NTSC	M	-	110/240 60Hz
ALBANIA	PAL	B	G	220 50Hz
ALGERIA	PAL	B	-	120/220 50Hz
ANDORRA	SECAM(V)/PAL	L	L	220 50Hz
ANGOLA	PAL	I	-	220 50Hz
ANTIGUA	NTSC	M	-	230 60Hz
ARGENTINA	PAL-N	N	N	220 50Hz
AUSTRALIA	PAL	B	B	240 50Hz
AUSTRIA	PAL	B	B	200 50Hz
AZERBAIJAN	SECAM(H)	D	K	220 50Hz
BAHAMAS	NTSC	M	-	110/240 60Hz
BAHRAIN	PAL	B	G	220 50/60Hz
BANGLADESH	PAL	B	-	220/230 50Hz
BARBADOS	NTSC	M	-	220 50Hz
BELARUS	SECAM	D	K	220 50Hz
BELGIUM	PAL	B	H	110/220 50Hz
BELIZE	NTSC	M	-	110 60Hz
BENIN	SECAM(V)	K1	-	220 50Hz
BERMUDA	NTSC	M	-	120/240 60Hz
BOLIVIA	NTSC M N	M	N	110/220 50Hz
BOSNIA HERZEGOVINIA	PAL	B	H	220 50Hz
BOTSWANA	PAL	-	-	220 50Hz
BRAZIL	PAL M	M	M	110/220 60Hz
BRITISH VIRGIN ISLANDS	NTSC	M	-	110/240 60Hz
BRUNEI	PAL	B	-	230 50Hz
BULGARIA	SECAM(H)	D	K	220 50Hz
BURMA	NTSC	-	-	120/240 60Hz
CANADA	NTSC	M	M	120 60Hz
CANARY ISLANDS	PAL	B	G	110/220 50Hz
CENTRAL AFRICAN REPUBLIC	SECAM	K1	-	220 50HZ
CHAD	SECAM(V)	D	-	220 50Hz
CHILE	NTSC	M	-	220 50Hz
CHINA	PAL	D	-	220 50Hz
COLOMBIA	NTSC	M	-	110 60Hz
CONGO	SECAM(V)	D	-	220 50Hz
COSTA RICA	NTSC	M	-	120 60Hz
CROATIA	PAL	B	G	220 50Hz
CUBA	NTSC	M	-	120 60Hz
CYPRUS (GREEK)	SECAM(H)	B	G	240 50Hz
CYPRUS (TURKISH)	PAL	B	G	240 50Hz
CZECH REPUBLIC	SECAM(H)	D	K	230 50Hz
DENMARK	PAL	B	G	220 50Hz
DOMINICAN REPUBLIC	NTSC	M	M	110 60Hz
ECUADOR	NTSC	M	M	220 60Hz
EGYPT	SECAM(H)	B	G	120/220 50Hz
EL SALVADOR	NTSC	M	-	120/230 60Hz
ESTONIA	SECAM(H)	D	K	220 50Hz
ETHIOPIA	PAL	B	-	220 50Hz
FIJI	NTSC	M	-	120 60Hz
FINLAND	PAL	B	G	220 50Hz
FRANCE	SECAM(V)	L	L	220 50Hz
GABON	SECAM(V)	K1	-	220 50Hz
GAMBIA	PAL	I	I	230 60Hz
GEORGIA	SECAM(H)	D	K	220 50Hz

COUNTRY	COLOR SYSTEM	VHF	UHF	MAINS ELECTRICITY
GERMANY	PAL	B	G	220 50Hz
GHANA	PAL	B	-	220 50Hz
GIBRALTAR	PAL	B	G	240 50Hz
GREECE	SECAM(H)	B	G	220 50Hz
GREENLAND	PAL	B	-	220 50Hz
GUATEMALA	NTSC	M	M	120/240 60Hz
GUINEA	PAL	K1	-	220 50Hz
HAITI	NTSC	M	-	220 60Hz
HAWAII	NTSC	M	-	120 60Hz
HOLLAND	PAL	B	G	220 50Hz
HONDURAS	NTSC	M	-	120 60Hz
HONG KONG	PAL	-	I	220 50Hz
HUNGARY	SECAM(H)	D	K	220 50Hz
ICELAND	PAL	B	G	240 50Hz
INDIA	PAL	B	-	240 50Hz
INDONESIA	PAL	B	-	110/220 50Hz
IRAN	SECAM(H)	B	-	220 50Hz
IRAQ	SECAM(H)	B	-	220 50Hz
IRELAND	PAL	I	I	220 50Hz
ISRAEL	PAL	B	G	220 50Hz
ITALY	PAL	B	G	220 50Hz
JAMAICA	NTSC	M	-	110 50Hz
JAPAN	NTSC	M	M	110 60Hz
JORDAN	PAL	B	G	220 50Hz
KAZAKHSTAN	SECAM(H)	D	K	220 50Hz
KENYA	PAL	B	G	230 50Hz
KOREA NORTH	SECAM	D	K	220 50Hz
KOREA SOUTH	NTSC	M	-	110 60Hz
KUWAIT	PAL	B	G	240 50Hz
LAOS	PAL-M	M	-	220 50Hz
LATVIA	SECAM(H)	M	-	220 50Hz
LEBANON	PAL	B	G	220 50Hz
LIBERIA	PAL	B	-	110/240 60Hz
LIBYA	SECAM	B	G	120/230 50Hz
LITHUANIA	SECAM(H)	D	K	220 50Hz
LUXEMBOURG	PAL/SECAM	B/L	G	220 50Hz
MACEDONIA	PAL	B	G	220 50Hz
MADAGASCAR	SECAM(V)	K1	-	120/220 50Hz
MALAYSIA	PAL	B	G	230 50Hz
MALTA	PAL	B	G	240 50Hz
MAURITANIA	SECAM(V)	B	-	230 50Hz
MAURITIUS	SECAM(V)	B	I	230 50Hz
MEXICO	NTSC	M	-	110-125 60Hz
MONACO	SECAM(V)/PAL	L	L,G	220 50Hz
MONGOLIA	SECAM(V)	D	-	120 50Hz
MOROCCO	SECAM(V)	B	-	110/220 50Hz
MOZAMBIQUE	PAL	B	-	220 50Hz
NAMIBIA	PAL	I	-	220 50Hz
NEPAL	PAL	B	-	220 50Hz
NETHERLANDS	PAL	B	G	220 50Hz
NEW CALEDONIA	SECAM(V)	K1	-	220 50Hz
NEW ZEALAND	PAL	B	G	230 50Hz
NICARAGUA	NTSC	M	-	220 60Hz
NIGER	SECAM(V)	K1	-	220 50Hz
NIGERIA	PAL	B	G	240 50Hz
NORWAY	PAL	B	G	220 50Hz

COUNTRY	COLOR SYSTEM	VHF	UHF	MAINS ELECTRICITY
OMAN	PAL	B	G	240 50Hz
PAKISTAN	PAL	B	-	230 50Hz
PANAMA	NTSC	M	-	120 60Hz
PAPUA NEW GUINEA	PAL	B	G	240 50Hz
PARAGUAY	PAL-N	N	-	220 50Hz
PERU	NTSC	M	M	220 60Hz
PHILIPPINES	NTSC	M	-	110 60Hz
POLAND	SECAM(H)	D	K	220 50Hz
POLYNESIA	SECAM(V)	K	-	220 50Hz
PORTUGAL	PAL	B	G	220 50Hz
PUERTO RICO	NTSC	M	M	110/240 60Hz
QATAR	PAL	B	-	240 50Hz
ROMANIA	SECAM(H)/PAL	D	K	220 50Hz
RUSSIA	SECAM	D	K	220 50Hz
SAMOA	NTSC	M	-	230 50Hz
SAUDI ARABIA	SECAM(H)/PAL	B	G	120/220 50Hz
SENEGAL	SECAM(V)	K1	-	120 50Hz
SERBIA	SECAM(H)	D	K	220 50Hz
SEYCHELLES	PAL	B	-	230 50Hz
SIERRA LEONE	PAL	B	-	230 50Hz
SINGAPORE	PAL	B	-	230 50Hz
SLOVAKIA	SECAM(H)	D	K	220 50Hz
SLOVENIA	PAL	B	G	220 50Hz
SOMALIA	PAL	B	-	220 50Hz
SOUTH AFRICA	PAL	I	I	230 50Hz
SPAIN	PAL	B	G	120/220 50Hz
SRI LANKA	PAL	B	-	230 50Hz
SUDAN	PAL	B	-	240 50Hz
SWEDEN	PAL	B	G	220 50Hz
SWITZERLAND	PAL	B	G	110/220 50Hz
SYRIA	PAL	-	G	110/220 50Hz
TAHITI	SECAM(V)	K	-	110/220 60Hz
TAJIKISTAN	SECAM	D	K	220 50Hz
TAIWAN	NTSC	M	-	110 60Hz
TANZANIA	PAL	B	G	230 50Hz
THAILAND	PAL	B	-	220 50Hz
TOGO	SECAM(V)	K1	-	220 50Hz
TRINIDAD & TOBAGO	NTSC	M	-	110/230 60Hz
TUNISIA	SECAM(V)	B	G	110/220 50Hz
TURKEY	PAL	B	G	110/220 50Hz
UGANDA	PAL	D	K	220 50Hz
UKRAINE	SECAM	B	G	220/240 50Hz
UNITED ARAB EMIRATES	PAL	B	-	240 50Hz
UNITED KINGDOM	PAL	-	I	240 50Hz
URUGUAY	PAL-N	N	-	220 50Hz
USA	NTSC	M	M	110 60Hz
UZBEKISTAN	SECAM	D	K	220 50Hz
VANUATU	PAL	-	-	220 50Hz
VATICAN	PAL	B	G	220 50Hz
VENEZUELA	NTSC	M	-	120/240 60Hz
VIETNAM	NTSC/SECAM(V)	M,D	-	220 50Hz
YEMEN	PAL	B	-	220 50Hz
YUGOSLAVIA	PAL	B	G	220 50Hz
ZAIRE	SECAM(V)	K1	-	220 50Hz
ZAMBIA	PAL	B	-	220 50Hz
ZANZIBAR	PAL	I	I	220 50Hz
ZIMBABWE	PAL	B	-	230 50Hz



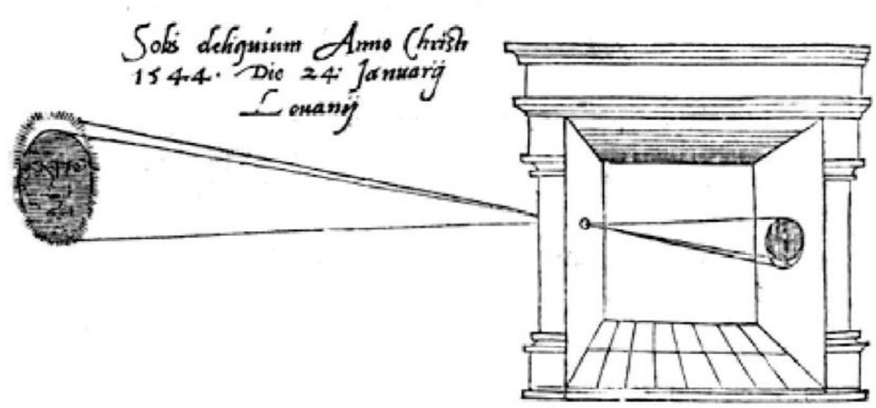
5. CCTV cameras

The very first and most important element in the CCTV chain is the element that captures the images – the camera.

General information about cameras

The term ***camera*** comes from the Latin ***camera obscura***, which means "dark room."

This type of room was an artist's tool in the Middle Ages. Artists used a lightproof room, in the form of a box, with a convex lens at one end and a screen that reflected the image at the other, to trace images and later produce paintings.



In the nineteenth century, "camera" referred to a device for recording images on film or some other light-sensitive material. It consisted of a lightproof box, a lens through which light entered and was focused, a shutter that controlled the duration of the lens opening, and an iris that controlled the amount of light that passed through the glass.

Joseph Nicéphore Niépce produced the first negative film image in 1826. This is considered the birth of photography. Initially, such photographic cameras did not differ much from the ***camera obscura*** concept. They were in the form of a black box, with a lens at the front and a film plate at the back. The initial image setup and focusing were done on an upside-down projection, which a photographer could see only when he or she was covered with a black sheet.

The first commercial photographic cameras had a mechanism for manual transport of the film between exposures and a viewfinder, or eyepiece, that showed the approximate view as seen by the lens.

Today, we use the term ***camera*** in film, photography, television, and multimedia. Cameras project images onto different targets, but they all use light and lenses.

To understand CCTV you do not need to be an expert in cameras and optics, but it helps if you understand the basics. Many things are very similar to what we have in photography, and since every one of us has been, or is, a family photographer, it will not be very hard to make a correlation between CCTV and photography or home video. In photographic and film cameras, we convert the optical information (images) into a chemical emulsion imprint (film). In television cameras, we convert the optical information into electrical signals. They all use lenses with certain focal lengths and certain angles of

view, which are different for different formats.

Lenses have a limited resolution and certain distortions (or aberrations), but this is more obvious in the film cameras. This is because the film resolution is still far better than the electronic camera resolution, although there are higher resolution chips coming out daily.

To illustrate, high-resolution CCD chips in CCTV these days have about 752 × 582 pixels (picture elements), while 100 ISO 35 mm color negative film has a resolution equivalent to 8000 × 6000 elements (film grains). This is based on a typical film resolution of 120 lpm.



Photo courtesy of Sarnoff Corp.

One of the very early television cameras from 1931

In 1997, another type of camera emerged on the market. This camera is used with computers for both video conferencing and digital image storage. A camera like this uses a CCD chip as an imaging device, but instead of producing analog electronic signal or projecting the image on film, it converts the image to digital format and stores it on a micro disk or RAM-card in the camera, so it can be transferred to a computer. Although most of such cameras produce still images, models with real-time video in digital format are already appearing.

Tube cameras

The first experiments with television cameras, as mentioned earlier, were made in the 1930s by the Russian-born engineer Vladimir (Vlado) Zworykin (1889–1982). His first camera, made in 1931, focused the picture onto a mosaic of photoelectric cells. The voltage induced in each cell was a measure of the light intensity at that point and could be transmitted as an electrical signal. The concept, with small modifications, remained the same for decades.

Those first cameras were made with a glass tube and a light-sensitive phosphor coating on the inside of the glass. We now call them ***tube cameras***.

Tube cameras work on the principles of ***photosensitivity***, based on the photo-effect. This means the light projected onto the tube phosphor coating (called the ***target***) has sufficient energy to cause the ejection of electrons from the phosphor crystal structure. The number of electrons is proportional to the light, thus forming an electrical representation of the light projection.

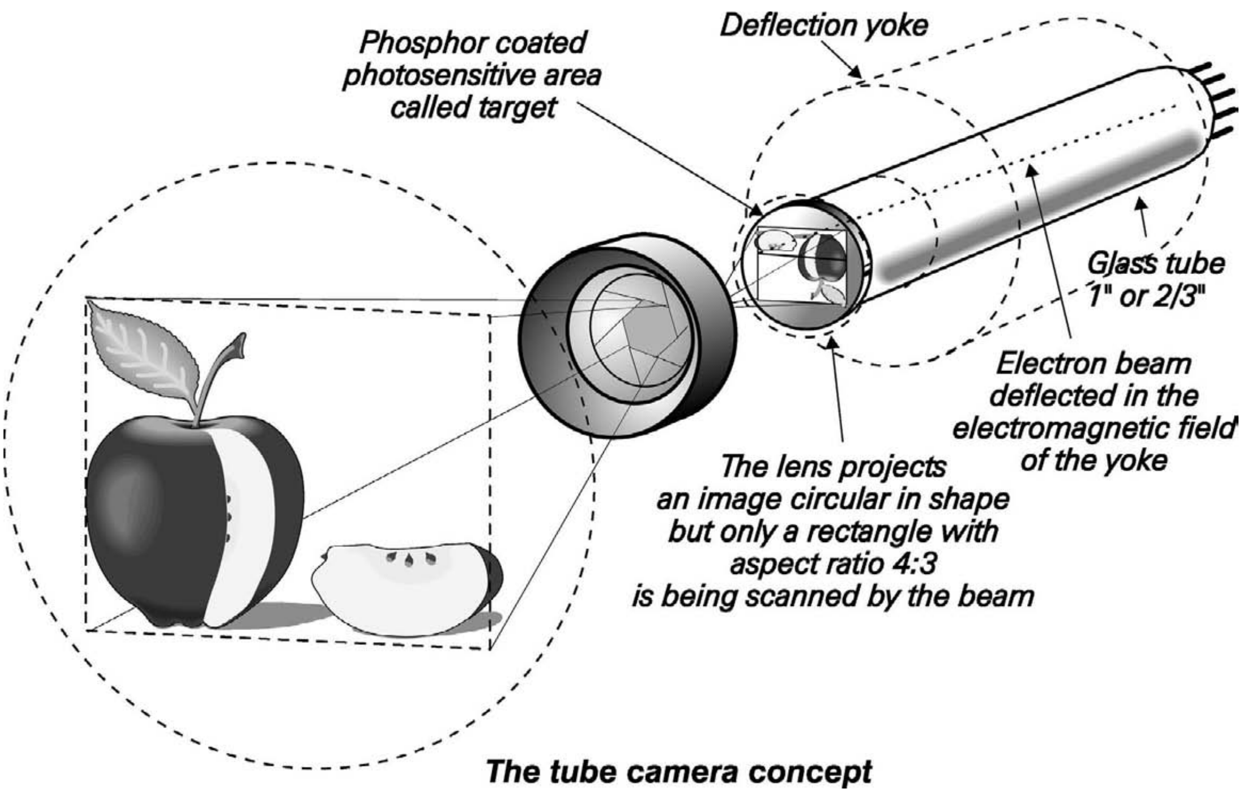


A studio tube camera from 1952

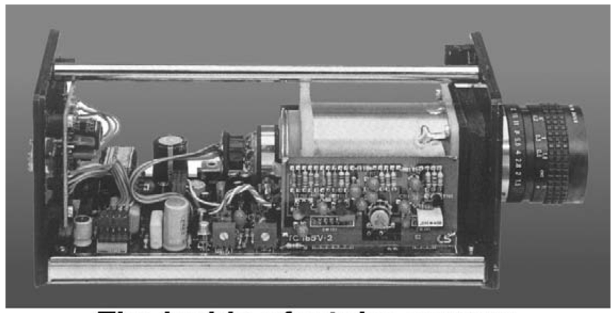
There were basically two main types of tubes used in the early days of CCTV: Vidicon and Newvicon.

Vidicon was cheaper and less sensitive. It had a so-called ***automatic target voltage control***, which effectively controlled the sensitivity of the Vidicon and, indirectly, acted as an electronic iris control, as we know it today on CCD cameras. Therefore, Vidicon cameras worked only with manual iris lenses. The minimum illumination required for a B/W Vidicon camera to produce a signal was about 5 ~ 10 lux reflected from the object when using an F-1.4 lens.

Newvicon tube cameras were more sensitive (down to 1 lux) and more expensive, and required auto iris lenses. Their physical appearance was the same as the Vidicon tube, and one could hardly determine which type was which by just looking at the two. Only an experienced CCTV technician could notice the slight difference in the color of the target area: the Vidicon has a dark violet color, while the Newvicon has a dark bluish color. The electronics that control these two types of tubes are different, and on the outside of the camera the Newvicon type has an auto iris connection.



The tube camera concept



The inside of a tube camera

All tube cameras use the principles of electromagnetism, where the electron beam scans the target from the inside of the tube. The beam is deflected by the locally produced EMF which is generated by the camera electronics. The more light that reaches the photoconductive layer of the target, the lower its local resistance will be. **When an image is projected, it creates a potential map of itself by the photosensitivity effect**. When the analyzing electron beam scans the photosensitive layer, it neutralizes the positive charges created, so that a current flow through the local resistor occurs. When the electron beam hits a particular area of the potential map, an electrical current proportional to the amount of light is discharged. This is a very low current, in the order of pico-Amperes (pA = 10^{-12} A), which is fed into a very high-input impedance video preamplifier, from which a video voltage signal is produced. For a tube camera it is important to have a thin and uniform photo layer. This layer produces the so-called ***dark current***, which exists even if there is no image projected by the lens (iris closed).

After a signal has been formed, the rest of the camera electronics add sync pulses, and at the output of the camera we get a complete video, known as a ***composite video signal***.

There are a few important concepts used in the operation of tube cameras, which we need to briefly explain in order to appreciate the differences between this and the new, CCD, technology.

The first concept is the **physical bulkiness of the camera** as such, due to the glass tube, electromagnetic deflection yoke around the tube, and the size of the rest of the electronic components in the era when surface mount components were unknown. This made tube cameras quite big.



Comparison of the physical size of a tube and a CCD chip

The second concept is the **need for a precise alternating electromagnetic field** (EMF) which will force the electron beam to scan the target area as per the television recommendations. To use an EMF to do the scanning means the external EMF of some other source may affect the beam scanning, causing picture distortions.

Third is the **requirement for a high voltage** (up to 1000 V), which accelerates the electron beam and gives it straight paths when scanning. Consequently, high-voltage components need to be used in the camera, which are always a potential problem for the electronic circuit's stability. Old and high-voltage capacitors may start leaking, moisture can create conductive air around the components, and electric sparks may be produced.

Fourth, there is the need for a phosphor coating of the target, which converts the light energy into electrical information. The phosphor as such is subject to constant electron bombardment that wears it out. Therefore, **the life expectancy of a tube phosphor coating is limited**. With constant camera usage, as is the case in CCTV, a couple of years will be the realistic life expectancy, after which the picture starts to fade out, or even an imprinted image will develop if the camera constantly looks at the same object. As a result, we can see pictures from a tube camera where, when people move, they appear as ghostlike figures, since they are semitransparent to the imprinted image.

And the fifth feature, conceptually different from the CCD cameras used today (and, again, this feature can be considered as a drawback) and inherently part of the tube camera design itself, consists of **geometrical distortions** due to the beam hitting the target at various angles. The path of the electron beam is shorter when it hits the center of the target as compared to when it scans the edges of the tube. Therefore, certain distortions of the projected image are present. In a lot of tube camera designs, we will find some magnetic and electronic corrections for such distortions, which means every time a tube needs to be replaced, all of these adjustments have to be remade.

With the new CCD technology, none of the above problems exists in cameras. One tube's feature, however, was very hard to beat in the early days of the CCD technology. This was the resolution of a good tube camera. Vertical resolution is dependent on the scanning standard, and this would be, more or less, the same at both, CCD and tube cameras, but the horizontal resolution (i.e., the number of vertical lines that can be reproduced) depends on the thickness of the electron beam. Since this can be quite successfully controlled by the electronics itself, very fine details can be reproduced (i.e., analyzed while scanning).

Initially, with the CCD design, microelectronics technology was not able to offer picture elements (pixels) of the CCD chip smaller than the beam cross section itself. This means that in the very beginning of CCD technology, the resolution lagged well behind that of the tube cameras.



CCD Camera

CCD cameras

In the 1970s, when personal computers were born, experiments were made with solid-state electronic elements called ***charge-coupled devices*** (CCD), which were initially intended to be used as memory devices.

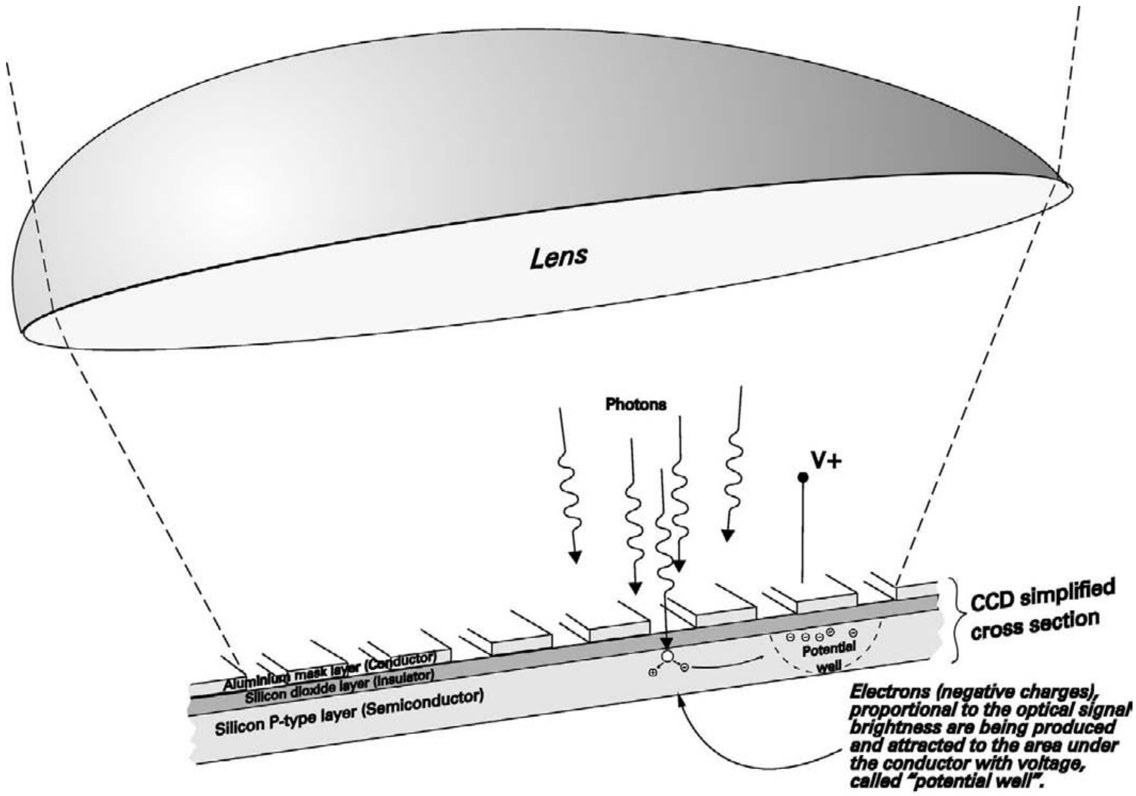
Very soon it was found that CCDs are very sensitive to light, so they could be used more effectively as imaging devices than as memory devices.

The basic principle of CCD operation is the storing of the information of electrical charges in the elementary cells and then, when required, shifting these charges to the output stage.

When a CCD chip is used as an imaging device, the shifting concept stays the same, but instead of injecting charge packets as digital information (which would be the case if the CCD chip is used as a memory device), we have a **photo-effect generating electrons proportional to the amount of light falling on the imaging area**, and then, these charges are shifted out vertically and/or horizontally, in the same manner as shift registers in digital electronics shift binary values.



Fifteen years apart, and they do the same job (tube and CCD camera).



Electrons in a CCD chip are generated by photons.

So, in effect, we have charge packets, once they have been collected in each photosensitive cell, "sliding down" to the output stage by using charge-coupling methods. Thus, an electrical coupling is done by means of voltage and timing manipulation of each cell, called a picture element (or **pixel)**.

One of the pioneers of CCD technology, Gilbert Amelio, in his article "Charge Coupled Imaging Devices" written in 1974, describes charge coupling as "a collective transfer of all the mobile electric charge stored within a semiconductor storage element to a similar, adjacent storage element by the external manipulation of voltages. The quantity of the stored charge in this mobile packet can vary widely, depending on the applied voltage and on the capacitance of the storage element. The amount of electric charge in each packet can represent information."

The construction of CCD chips is in the form of either a line area (linear CCD) or a two-dimensional matrix (array CCD). It is important to understand that **they are composed of discrete pixels, but CCDs are not digital devices**. Each of these pixels can have any number of electrons, proportional to the light that falls onto it, thus representing **analog information**.

These discrete packets of electrons are then transferred (once the exposure time is over), by simultaneous shifting of row and column packets, to the output stage of the chip.

This is why we can say **CCDs are, in essence, analog shift registers sensitive to light.**

Today, CCDs are not used as memory devices, but mostly as imaging devices. They can be found in many objects of daily use: facsimile machines use linear CCD chips; picture and OCR scanners also use linear

CCDs; many auto-focusing photographic cameras use CCD chips for auto-focusing; geographic aerial monitoring, spacecraft planet scanning, and industrial inspection of materials also use linear CCD cameras; and last, but not least, most of the television cameras these days, both in broadcast and CCTV, use CCD chips.



Line scan CCD chips are used in satellite imaging.

CCD cameras have many advantages (in design) over the tube cameras, although, as mentioned earlier, in the beginning it was hard to achieve high-resolution similar to what the tube cameras had. These days, however, the technology is at such a level that high resolution is no longer a problem.

The main advantages that the CCD cameras have over tube cameras are:

- Very low minimum illumination performance (down to 0.1 lx at the object);
- No geometrical distortions due to a precise two-dimensional construction;
- Low power consumption;
- No need for high voltage for beam acceleration;
- Small size;
- No influence of external EMFs; and, most importantly,
- Unlimited lifetime of electrons generated by photo-effect.

As we said earlier, CCDs come in all shapes and sizes, but the general division is into linear and two-dimensional matrices. Linear chips are used in applications where there is only one direction of movement by the object (as with facsimile machines or scanners).

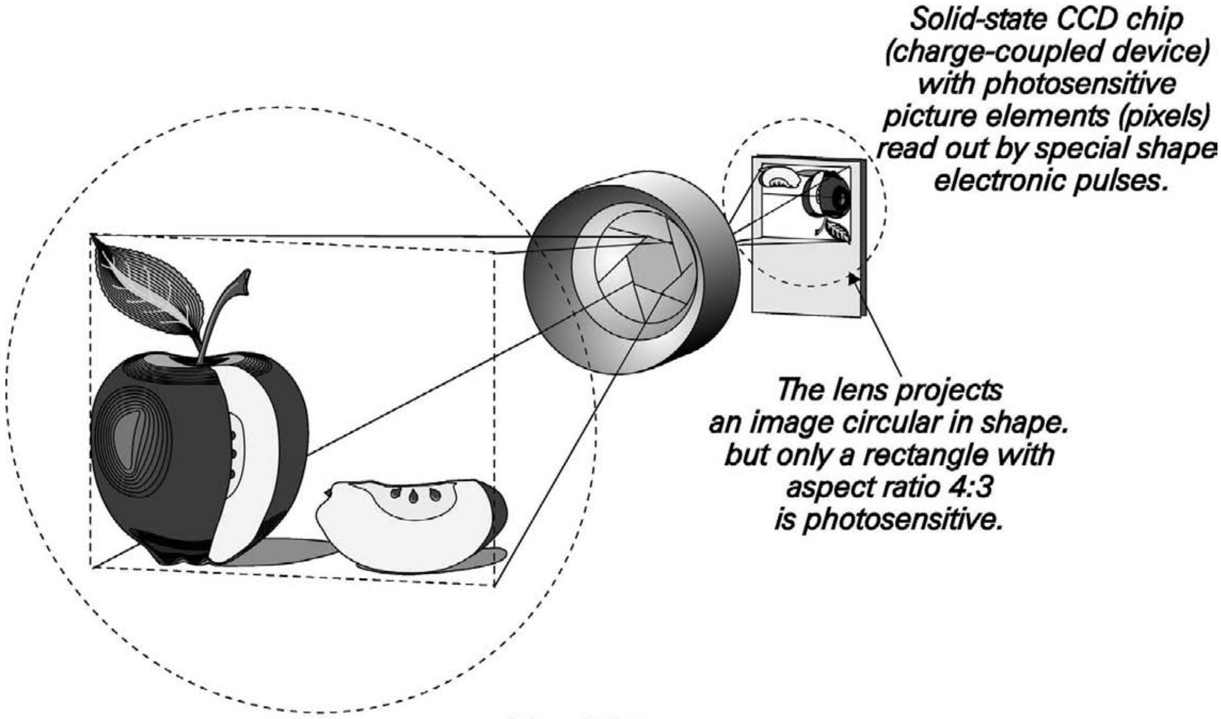
In CCTV we are only interested in two-dimensional matrices, the so-called 2/3", 1/2", 1/3", and 1/4" sizes.

As mentioned earlier, these numbers are **not the diagonal sizes of the chips**, as many assume, but rather they are the sizes people use to refer to the diameter of the tube that would produce such an image.

Sensitivity and resolution of the CCD chips

Comparing sensitivities will show us the advantage of CCD chips relative to the Vidicon and Newvicon tubes, but also relative to a film emulsion.

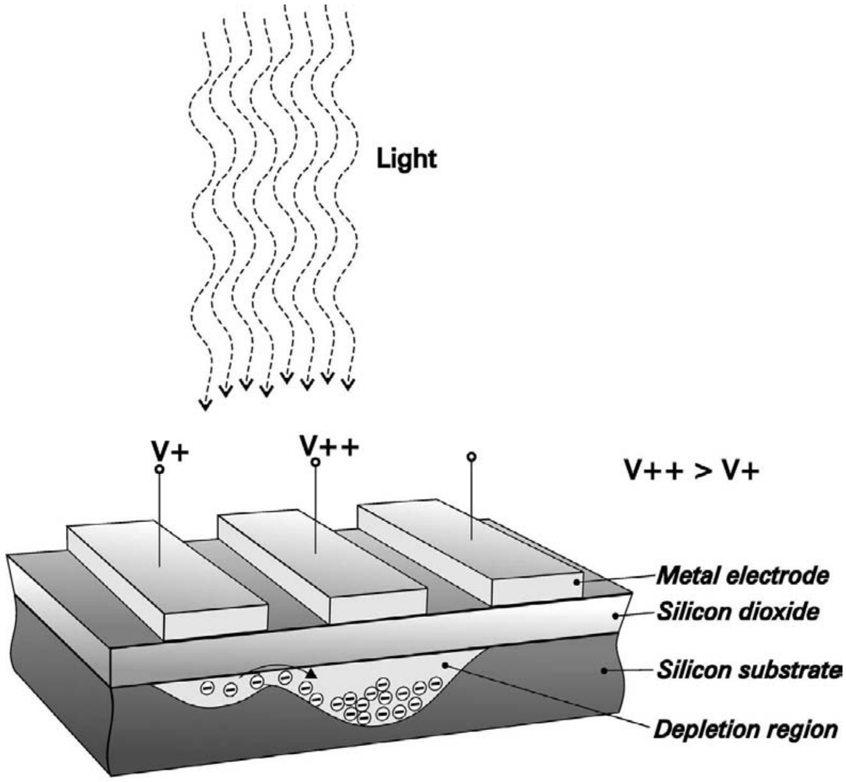
The 100 ISO film is the most commonly used in photography, although we can buy 200 ISO film (twice as sensitive) or 400 ISO (four times more sensitive than the 100 ISO film). Sometimes, we may even come across 1600 ISO film, and this is usually used for extremely low light level situations (at least in photographic terms).



The CCD concept

It can be shown that an average B/W CCD chip has a very high light sensitivity compared to a film emulsion. On a full sunny day, a typical 100 ISO film camera will require a setting of 1/125 s and F-16. When the same scene is observed by a CCD camera, of which the normal CCIR exposure speed is 1/50s, a lens with approximately F-1000 needs to be used (give or take an F-stop or two, since the camera's AGC plays a role too). If we convert the 1/50 to 1/125 (2.5 times shorter), in order to have the same exposure the lens needs to have an opening 2.5 F-stops wider, in order to compensate for the shortening of the exposure. This brings us from F-1000 to approximately F-400 (remember the F-numbers: 1.4, 2, 2.8, 4, 5.6, 8, 11, 16, 22, 32, 44, 64, 88, 128, 180, 250, 360, 500, 720, 1000, 1400, etc.). Now, in order to convert the sensitivity of the film emulsion to get from the 100 ISO settings of 1/125 and F-16 to the equivalent settings of a higher film sensitivity, and knowing that double sensitivity occurs with doubling the ISO number, we get 9.5 F-times from F-16 to F-400. And this is approximately $2^{9.5}$ = 720 times. So, **the average B/W CCD chip sensitivity, expressed in photographic ISO units, is approximately 100 ISO × 720 = 72,000 ISO!**

Similarly, we will find that **a color CCD camera has the equivalent sensitivity of approximately 5000 ISO**, which is still very high compared to the photographic standards. Admittedly, such a high sensitivity picks up quite a high noise, so in practice the sensitivity is reduced somewhat in order to minimize noise. Noise is proportional to the temperature, and unfortunately it cannot be avoided unless CCD chip is very cold. For special applications, such as astronomy, CCD chips are cooled down to -30º C, or even lower, in order to get clean image, with as little noise as possible.

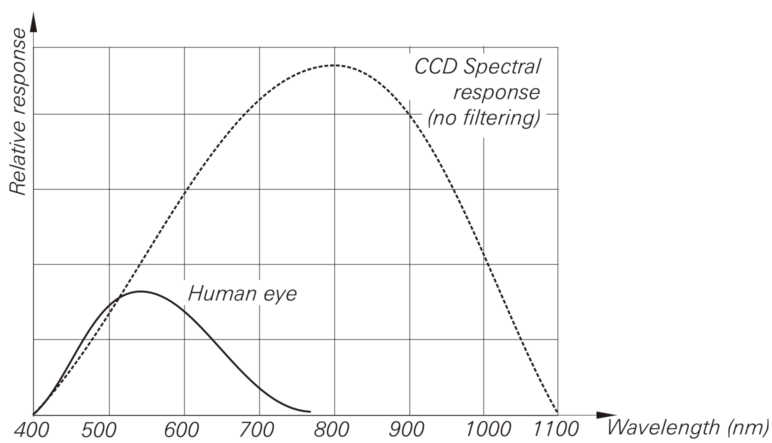


A CCD picture element

Chemical (film) photography is slowly but surely being replaced with electronic cameras using CCD chips. Such still cameras are not dependent on the TV standard; therefore, there is no practical limitation on the number of pixels and aspect ratio. Even as this book is being written, manufacturers are producing chips with an area size as small as 62 mm × 62 mm, with no less than 5120 × 5120 picture elements. As already mentioned, these are still cameras and should not be confused with CCTV cameras.

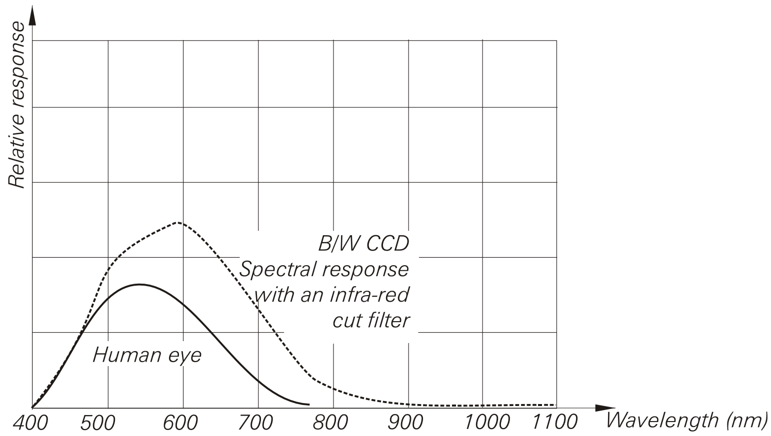
The spectral sensitivity of CCD chips varies with various silicon substrates, but the general characteristic is a result of the photo-effect phenomenon: **longer wavelengths penetrate deeper into the CCD silicon structure**. This refers to the red and infrared light. A typical CCD chip spectral curve is shown on the drawing below.

Even though this “penetration” may seem beneficial (CCD chips seem more sensitive), there are reasons for preventing some of the longer waves from getting too deep inside the chip. Such wavelengths might be so strong that they could produce electron carriers in areas that are not supposed to be exposed to light. As a result, the picture may lose details because the next-door pixels will melt their content into each other, losing high-resolution components



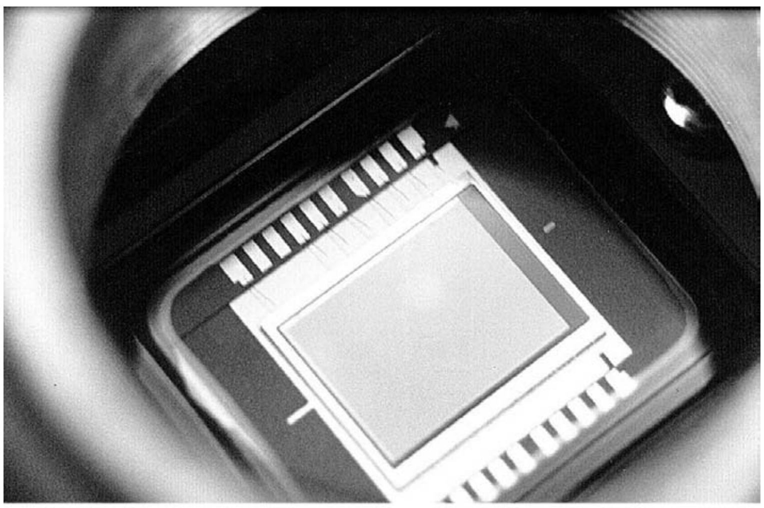
The eye’s and the CCD chip’s spectral sensitivity

and causing a "blooming effect." The masked areas, which are supposed to only temporarily store charges and are not supposed to be exposed to light, can also be affected, so that noise and smear increase significantly. Because of these reasons, special ***optical infrared cut filters*** have been introduced as part of a well-designed CCD camera. These filters are optically precise plan-parallel pieces of glass, mounted on top of the CCD chips. As the name suggests, they behave as optical low pass-filters, where the cutting frequency is near 700 nm, that is, near the color red.



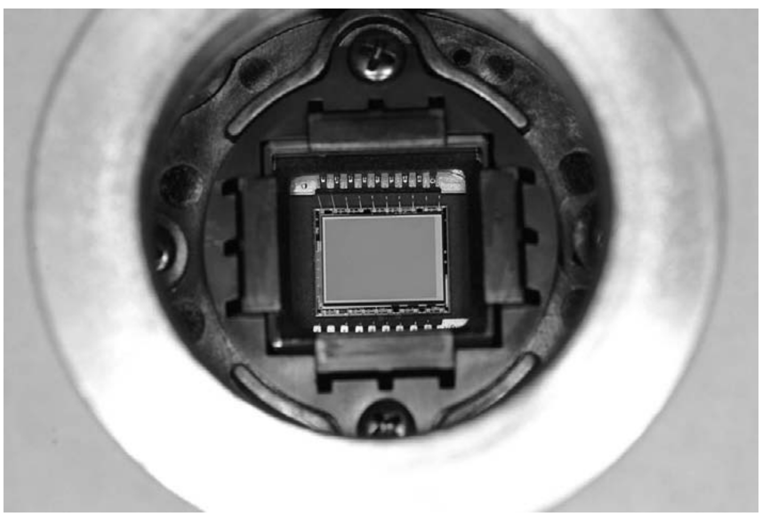
Infrared cut filter modifies the CCD response.

There are a number of manufacturers of B/W cameras, however, that prefer not to put such filters on their chips, to make their cameras more sensitive. This might be acceptable, especially when cameras for lower light levels need to be used or if infrared illuminators are to be part of the system. However, from a theoretical point of view **cameras *with* infrared cut filters will show better resolution** (compared to the same chip without an IR cut filter), **better S/N ratio, and more natural color-to-gray conversion**, at the expense of a not so low minimum illumination response.



B/W CCD camera chip without infrared cut filter

Color CCD cameras, on the other hand*, must* use an IR cut filter, as the CCD chip's spectral response, which we saw is different compared to that of the eye, must be made similar to the human eye's spectral sensitivity. This is also one of the reasons color CCD cameras are less sensitive than B/W.



Color CCD camera chip with infrared cut filter

A typical B/W CCD chip, without an infrared cut, can produce a reasonable level of video signal as low as 0.01 lx. The same camera with a filter will

be quoted 0.1 lx for the same object illumination.

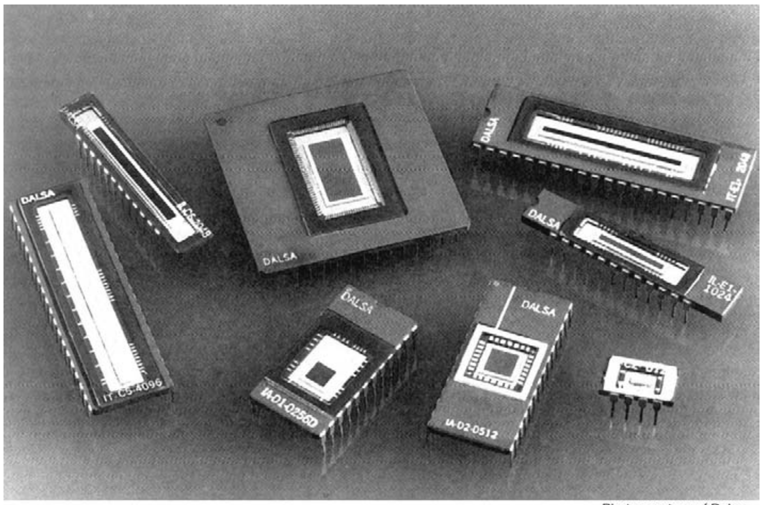


Photo courtesy of Dalsa

Various types of CCD chips

Color cameras these days are quoted to have 1 lx minimum illumination at the object, with an F-1.4 producing a video signal of a reasonable level (0.3 to 0.5 V).

The CCD technology is now at a stage where a few million pixels are no longer a problem. In digital photography, 6 million pixels CCD chip are very common, and now manufacturers are trying to go even higher. In the CCTV area, however, we are only limited with the analog resolution of the TV system. Because of that we do not have any higher than 752 × 584 pixels, for example, which counts a bit over 400,000 pixels. We will have more to say later on about resolution and how it is measured, but we should also mention some interesting CCD products, which, strictly speaking, are not CCTV cameras as such but offer high-resolution solutions.

One is the solution by Spectrum San Diego Inc., called SentryScope, which produces images with 21 million of pixels, using a 2048 pixel line scan CCD chip. The image is captured very similarly to how satellites scan the Earth, using a mirror that scans a wide area of around 10,000 pixels. This camera does not produce a video signal as such, but it captures only a few images per second, which, however, are extremely detailed.





Photo courtesy of Spectrum San Diego Inc.

The Sentry-Scope 21 million pixels CCD camera gives incredible details in one shot.



Photo courtesy of Co-Vi

The "nearly" HD CCTV camera

Other interesting new solutions are on the horizon. An example is the extended definition camera by Co-Vi, which utilizes some sort of extended definition CCD chip of 1280 × 720 pixels, which is then electronically cropped to produce a normal resolution video, but offers electronic panning and zooming across the nearly 1 million pixels real estate. So the effect to the user is that, even though a fixed camera is used, it is possible to zoom in a couple of times electronically into objects or pan around to see more details.

And yet another, also interesting, solution is by some designers where standard resolution CCD cameras are used, but they are arranged in a matrix of 3 × 3, or even 4 × 4 cameras, all looking at the same object but using a narrow angle of view lenses, which are positioned in such a way that they overlap only a little bit. The image obtained is then projected on a video wall made up of 3 × 3 or 4 × 4 monitors, offering a total resolution of 3.6 million pixels, or 6.4 million pixels. The end result is a large image with plenty of details, all of which can be recorded on a standard definition digital video recorder.

Types of charge transfer in CCDs

Matrix (array) CCD chips, as used in CCTV, can be divided into three groups based on the techniques of charge transfer.

The very first design, dating from the early 1970s, is known as ***frame transfer (FT)***. This type of CCD chip is effectively divided into two areas with an equal size, one above the other, an imaging and a masked area.

The **imaging area is exposed to light for 1/50 s** for a CCIR standard video (1/60 s for EIA). Then, **during the vertical sync period, all photogenerated charges** (electronically representing the optical image that falls on the CCD chip) **are shifted down to the masked area** (see the simplified drawing on the next page). Basically, the whole "image frame" comes down.

Note the upside-down appearance of the projected image, since that is how it looks in a real situation; that is, the lens projects an inverted image and the bottom right-hand pixel is recreated in the top left-hand corner when displayed on a monitor.

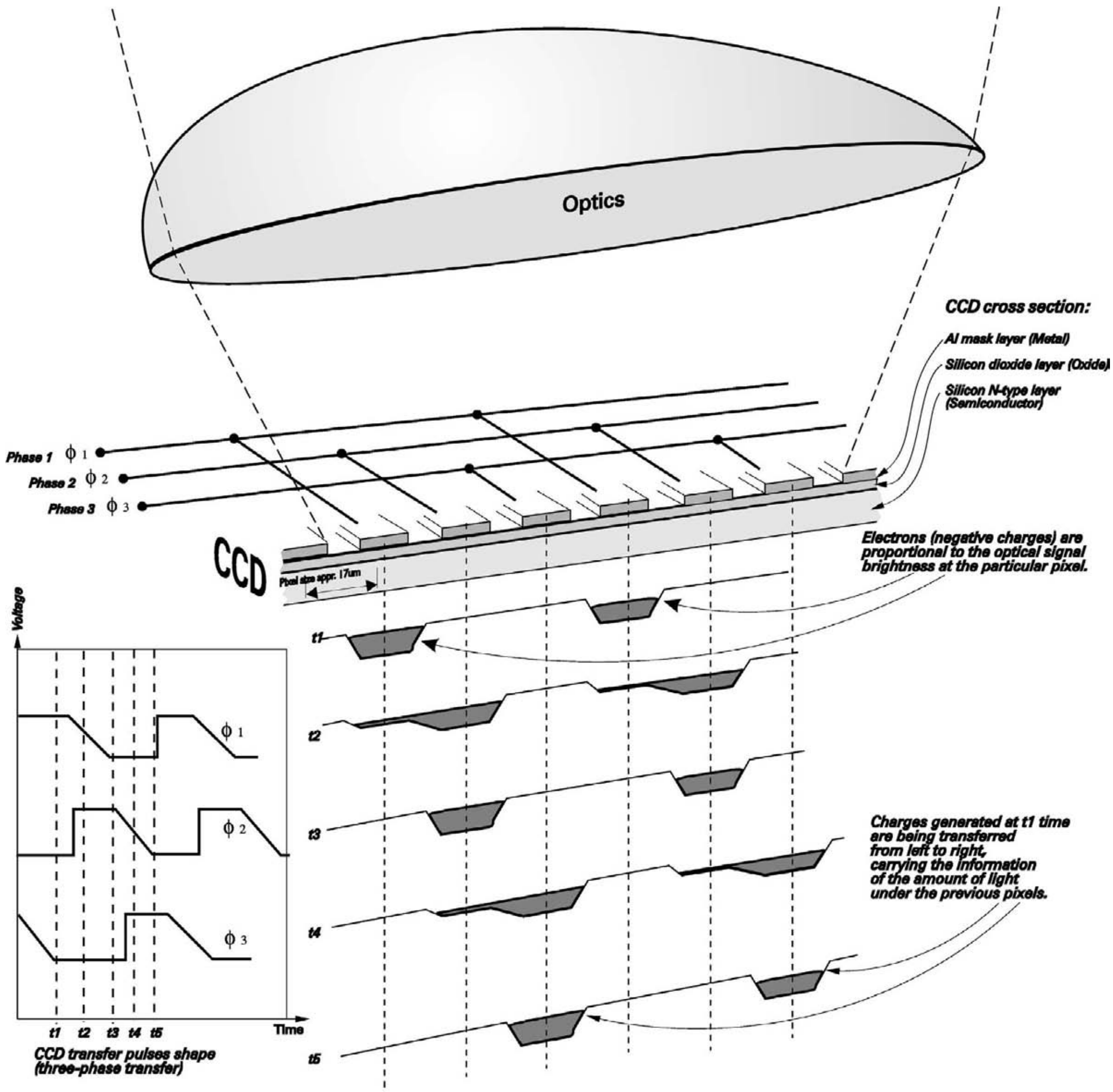
For the duration of the next 1/50 s, the imaging area generates the electrons of the new picture frame, while the electron packets in the masked area are shifted out horizontally, line by line. The electron packets (current) from each pixel are put together in one signal and converted into voltage, creating a TV line information.

Technically, perhaps, it would be more precise to call this mode of operation "field transfer" rather than "frame transfer," but the term ***field transfer*** has been used since the early days of CCD development and we will accept it as such.

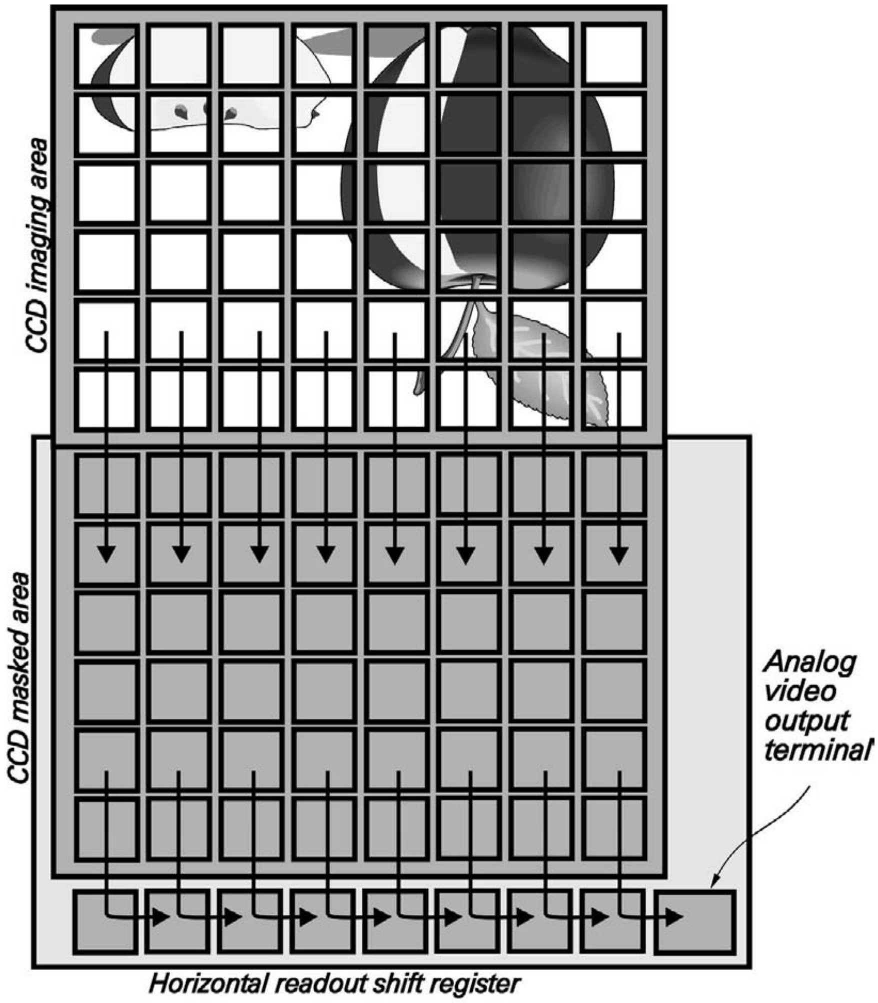
This first design of the CCD chip was good. It had surprisingly better sensitivity than Newvicon tubes

and much better than Vidicon, but it came with a new problem that was unknown to tube cameras: *vertical smearing*. In the time between subsequent exposures when the charge transfer was active, **nothing stopped the light from generating more electrons**. This is understandable since electronic cameras do not have a mechanical shutter mechanism as photographic or film cameras do. So where intense light areas were present in the image projection, vertical bright stripes would appear.

To overcome this problem, design engineers have invented a new way of transference called ***interline transfer (IT)***. The difference here is (see the simplified drawing) that the exposed picture is not transferred down during the vertical sync pulse period, but it is **shifted to the left masked area columns**. The imaging and masked columns are next to each other and interleave, hence the name,



Carge-coupled device principle of operation



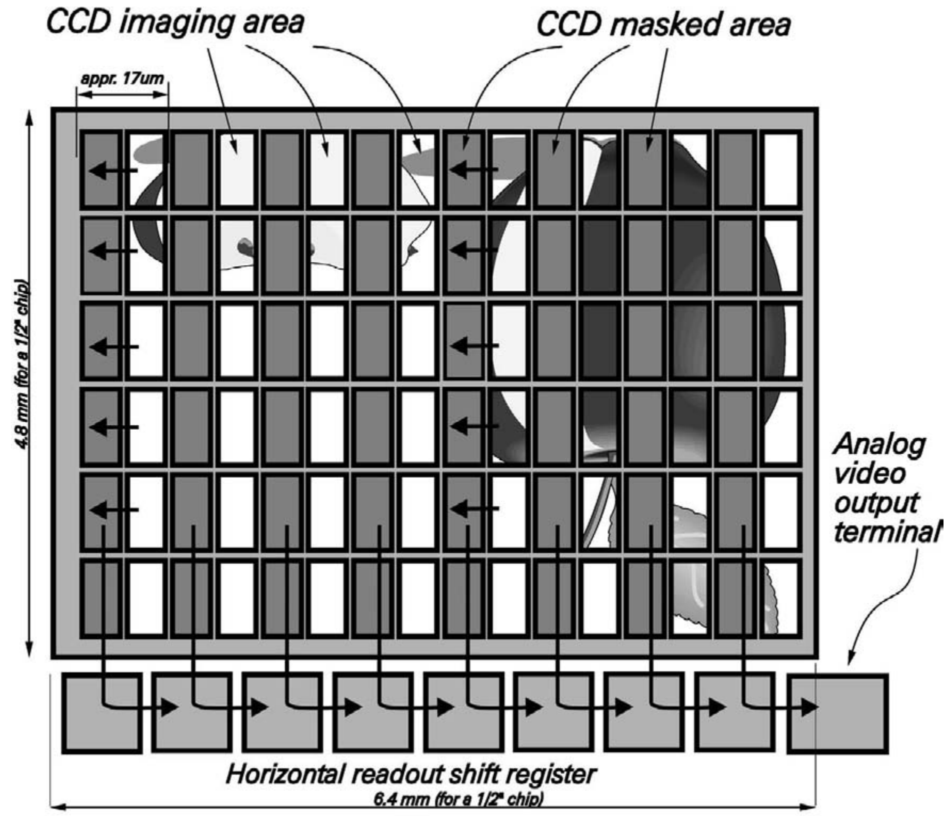
Frame transfer (FT) concept

interline. Since the masked pixel columns are immediately to the right of the imaging pixel columns, the shifting is considerably faster; therefore, there is not much time for bright light to generate an unwanted signal, the smear.

To be more precise, the smear is still generated but in a considerably smaller amount. As a result, we also have a much higher S/N ratio.

There is one drawback to the IT transfer chips, which is obvious from the concept itself: in order to add the masked columns next to the imaging columns on the same area as the previous FT design, the size of the light-sensitive pixels had to be reduced. This reduces the sensitivity of the chip. Compared to the benefits gained, however, this drawback is of little significance.

One new and interesting benefit is the **possibility of implementing an electronic shutter in the CCD design**. This is an especially attractive feature, where the natural exposure time of 1/50 s (1/60 for NTSC) can be electronically controlled and reduced to whatever shutter speed is necessary, still producing a 1 V_{pp} video signal.

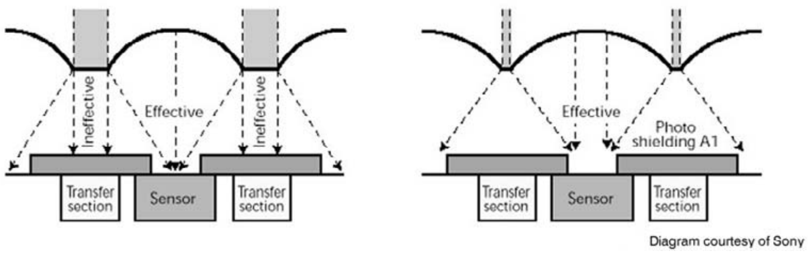


Interline transfer (IT) concept

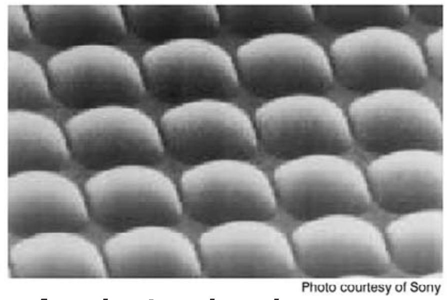
Initially, with the IT chip, manual control of the CCD-shutter was offered, but very soon an automatic version came out. This type of control is known as an automatic ***CCD-iris***, or ***electronic iris***. The electronic iris replaces the need for AI controlled lenses. So an MI lens can be used with an electronic iris camera even in an outdoor installation. It should be noted, however, that an **electronic iris cannot substitute the depth of field function** produced by the mechanical iris in a lens. Also, it should be remembered that when the electronic iris switches to higher shutter speeds, and due to lower charge transfer efficiency, the smear increases.

So, when the electronic iris is enabled, it switches from a normal exposure speed of 1/50 (1/60) to a higher one (shorter duration), depending upon the light situation. Theoretically, exposures longer than 1/50 s (1/60 s for EIA) could not be used because of loss of motion. With some CCD cameras, longer exposures are possible, and this mode of operation is called ***integration***. With some of the latest camera designs incorporating digital signal processing, integration is automatically turned on when object illumination falls below a certain level. This is especially helpful with color cameras, where low light level pictures are produced, which until now were possible only with B/W cameras. The price paid for this is the loss of smoothness in motion (in integration mode we cannot have 50 fields), which is substituted with a motion appearance similar to a playback from a TL VCR.

Reducing the pixel size in the IT design, we said, indirectly reduces the chip's minimum illumination performance. This problem can be solved with a very simple concept (technologically not as easy, however) of putting micro lenses on top of every pixel. Micro lenses concentrate all of the light that falls on them to a smaller area, that is, actually the pixel itself, and effectively increase the minimum illumination performance. The most common types of CCD cameras in CCTV today have IT chips.



Comparison between a conventional on-chip micro lens and the new Sony's Exwave concept



An electronic microscope photo of the on-chip micro lens structure

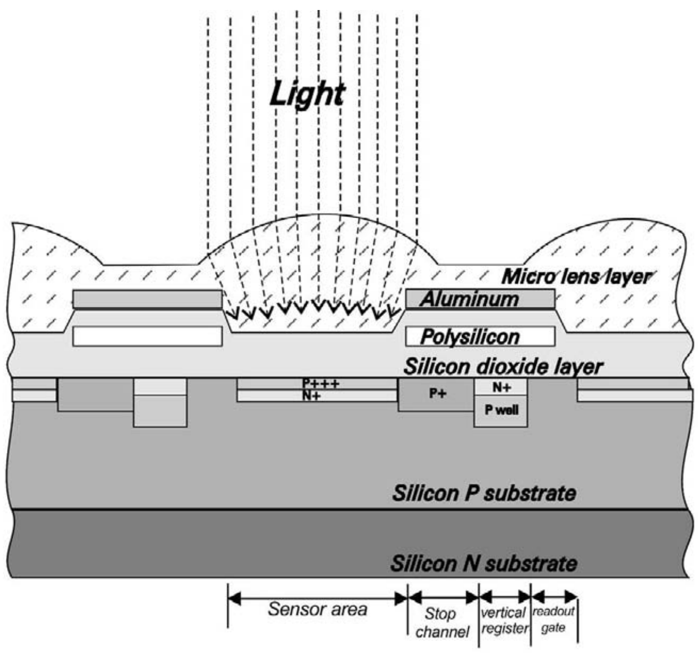
A typical cross section of an IT CCD chip with a micro lens on top of every pixel is shown on the drawing on the next page. As can be seen, the micro structure of the chip becomes quite complex when a high-quality signal needs to be produced.

The best design so far is the latest ***frame interline transfer (FIT)*** chip, offering all the features of the interline transfer plus even less smear and a better S/N ratio. As can be concluded from the simplified drawing, the FIT CCD works as an interline transfer in the top part of the chip, thus having the electronic iris control, but instead of holding the image in the masked columns for the duration of the next field exposure, it is shifted down to the better protected masked area.

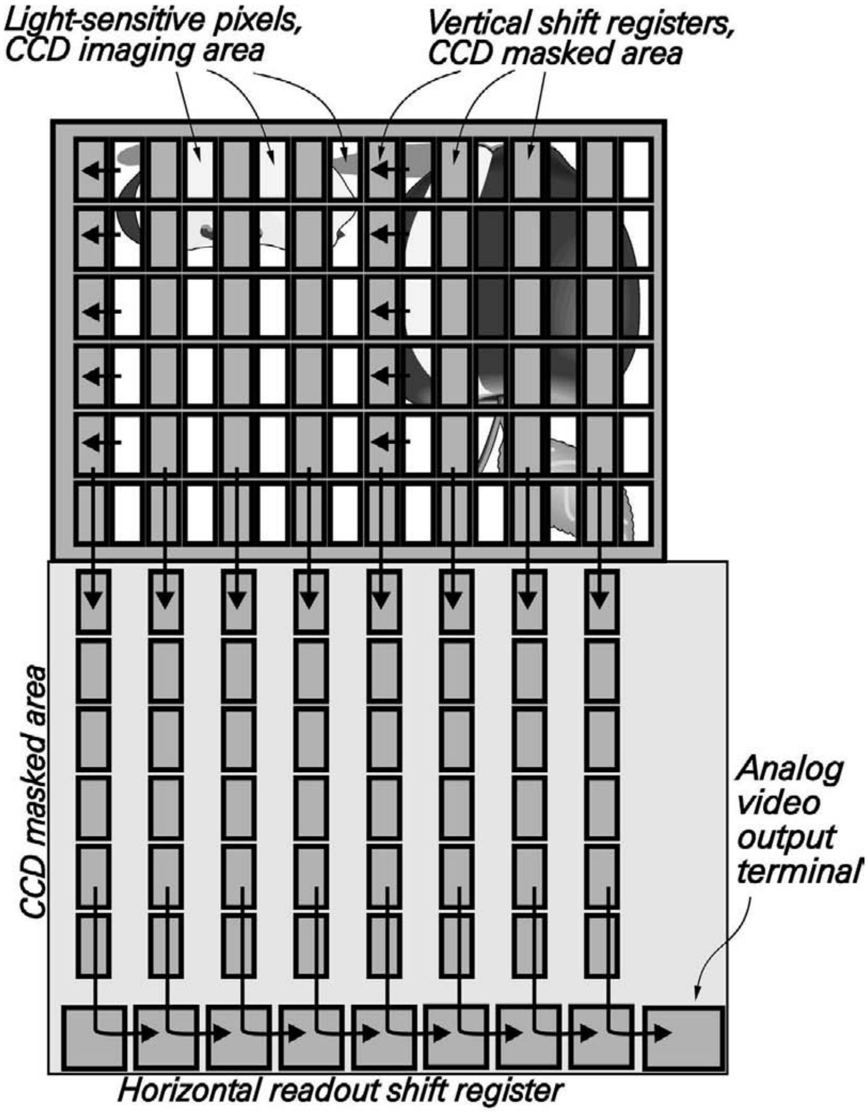
This is the reason for even less smearing in the FIT design, but there is also gain in the S/N ratio. Micro lenses are also used here to increase the minimum illumination performance. FIT chips have an even further advanced micro structure, with a lot of cells and areas designed to prevent spills of excessive charges to the area around, trap the thermally generated electrons, and so on. With all these fine tune-ups, FIT chips have a very high dynamic range, low smear, and high S/N ratio, which makes them ideal for external camera shooting and news gathering in broadcast TV. These types of cameras, in broadcast TV, are usually referred to as ***electronic news gathering*** cameras (ENG).

So, as it can be seen, these chips are expensive for CCTV, and their main use is in broadcast TV.

In the end we should point out that no matter how good the camera electronics are, if the source of information – the CCD chip – is of an inferior quality, the camera will be inferior too. The opposite statement is also true. That is, even if the CCD chip is of the best quality, if the camera electronics cannot process it in the best possible way, the total package becomes second class.



A typical structure of the cross section of a CCD chip with micro lens design



Frame interline transfer (FIT) concept

It should also be noted that most of the handful of chip manufacturers have CCD products of the same type divided into a few different classes, depending on the pixel quality and uniformity. Different camera manufacturers may use different classes of the same chip type. This is in the end reflected not only in the quality but also in the price of the camera.

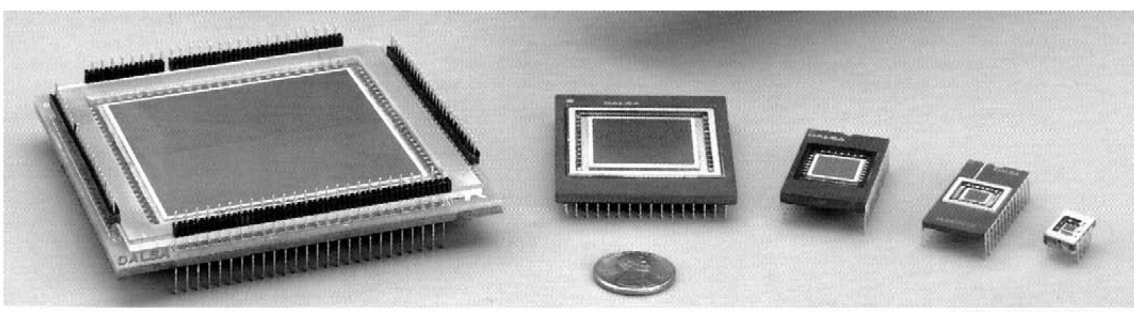


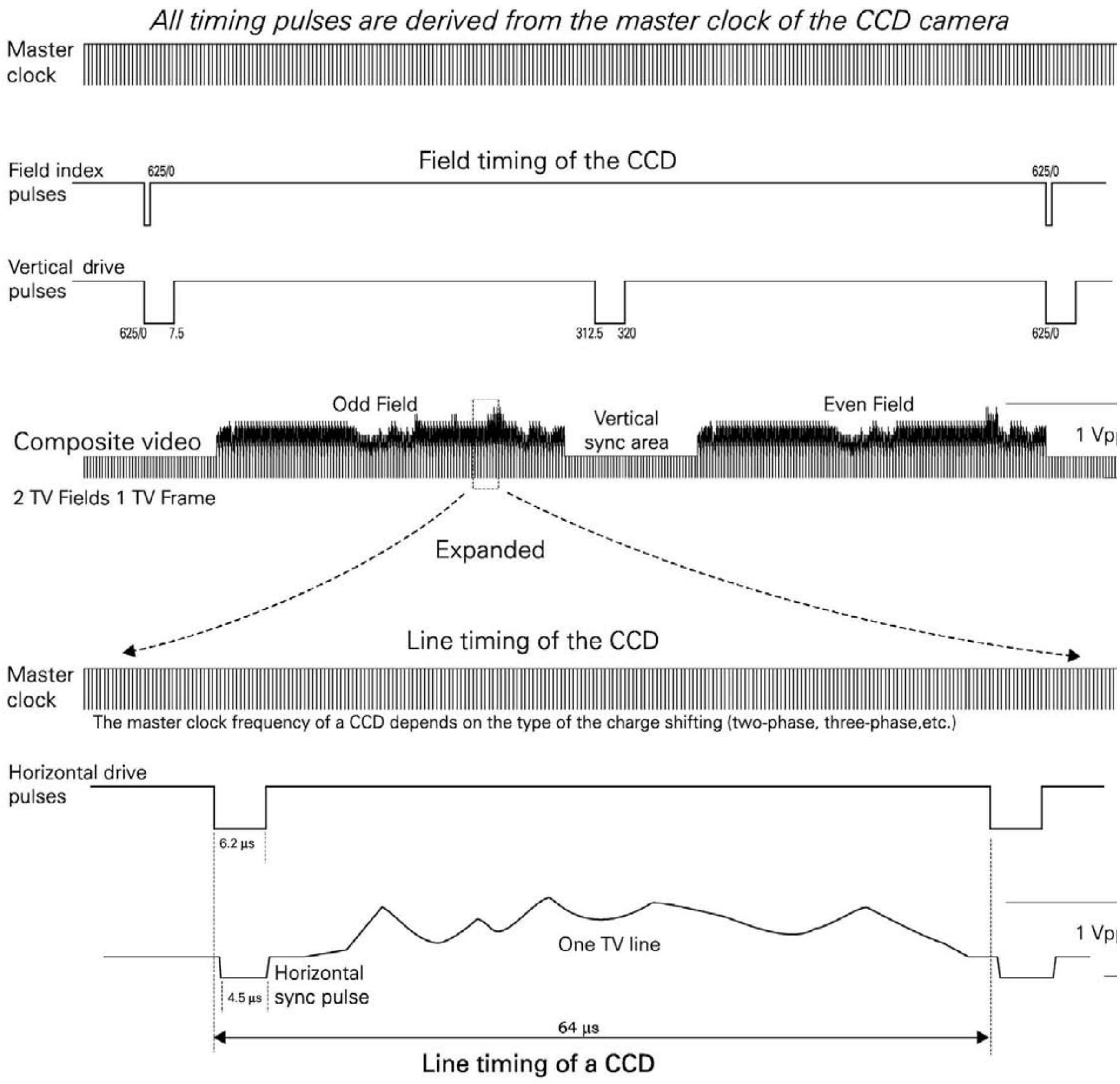
Photo courtesy of Dalsa

Array CCD chips come in various sizes.

Pulses used in CCD for transferring charges

The quality of a signal as produced by the CCD chip depends also on the pulses used for transferring charges. These pulses are generated by an internal crystal oscillator in the camera. This frequency depends on many factors, but mostly on the number of pixels the CCD chip has, the type of charge transfer (FT, IT, or FIT), as well as the number of phases used for each elementary shifting of charges; namely, the elementary shifting can be achieved with a two-phase, three-phase, or four-phase shift pulse. In CCTV, cameras with three-phase transfer pulses are the most common.

As you can imagine, the camera's crystal oscillator needs to have a frequency at least a few times higher than the signal bandwidth that a camera produces. All other syncs, as well as transfer pulses, are derived from this master frequency. The drawing shows how this charge transfer is performed with



Timing pulses in a CCD chip are derived from a master clock.

the three-phase concept.

The pulses indicated with ϕ_1, ϕ_2, and ϕ_3 are low-voltage pulses (usually between 0 and 5 V DC), which explains why CCD cameras have no need for high voltage, as was the case with the tube cameras.

The preceding schematic shows how video signal sync pulses are created using the master clock.

This is only one of many examples, but it clearly shows the complexity and number of pulses generated in a CCD camera.



A fixed camera dome with tinted glass

CCD chip as a sampler

As we said earlier, the CCD chip used in CCTV is a two-dimensional matrix of picture elements (*pixels*). The resolution that such a matrix produces depends on the number of pixels and the lens resolution. Since the latter is usually higher than the resolution of the CCD chip, we tend to not consider the optical resolution as a bottleneck. However, as mentioned in the heading on MTF, lenses are made with a resolution suitable for a certain image size, and care should be taken to use the appropriate optics with various chip sizes.

There is another important aspect of the CCD resolution to be taken into account, and this is the TV line noncontinuity. A TV line produced by a tube camera is obtained by a **continuous** beam scanning along the line. A CCD chip has **discrete** pixels and therefore the information contained in one TV line is composed of **discrete** values from each pixel. This method does not produce digital information but rather discrete samples. In a way, the CCD chip is an ***optical sampler***.

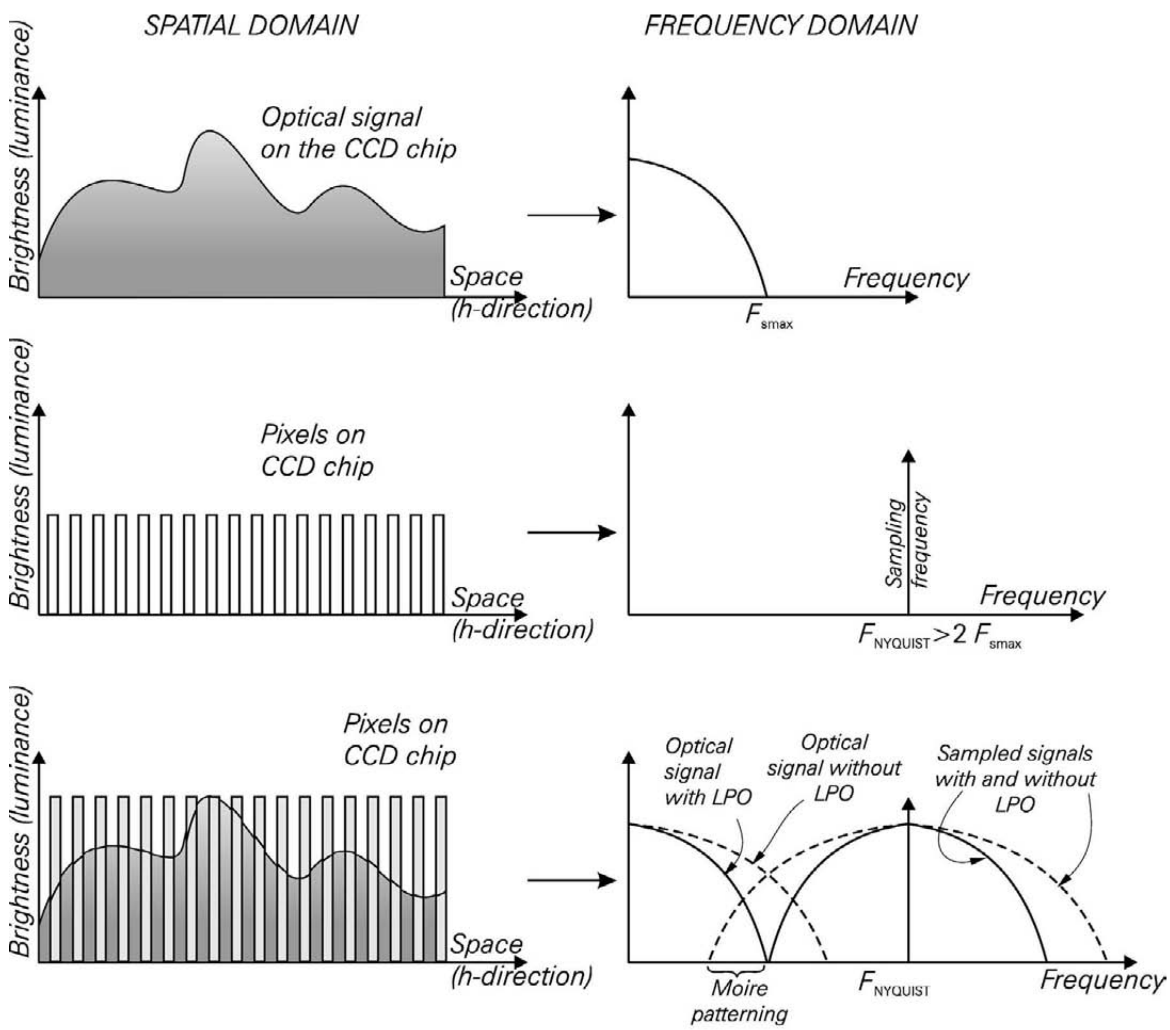
As with any other sampler, we do not get the total information of each line, but only discrete values at positions equivalent to the pixel positions.

To some, it may seem impossible to reproduce a continuous signal from only portions of the same. In 1928, however, Nyquist showed that a signal can be reconstructed perfectly, without any loss of information, if the sampling frequency is at least twice the bandwidth of the signal. **Samples of the signal in between the sampled points are not necessary**. This is a great theory, proven correct and used in many electronic samplers such as in CD-audio and video. The sampling frequency, which is equivalent to two times the bandwidth, is called the ***Nyquist frequency***.

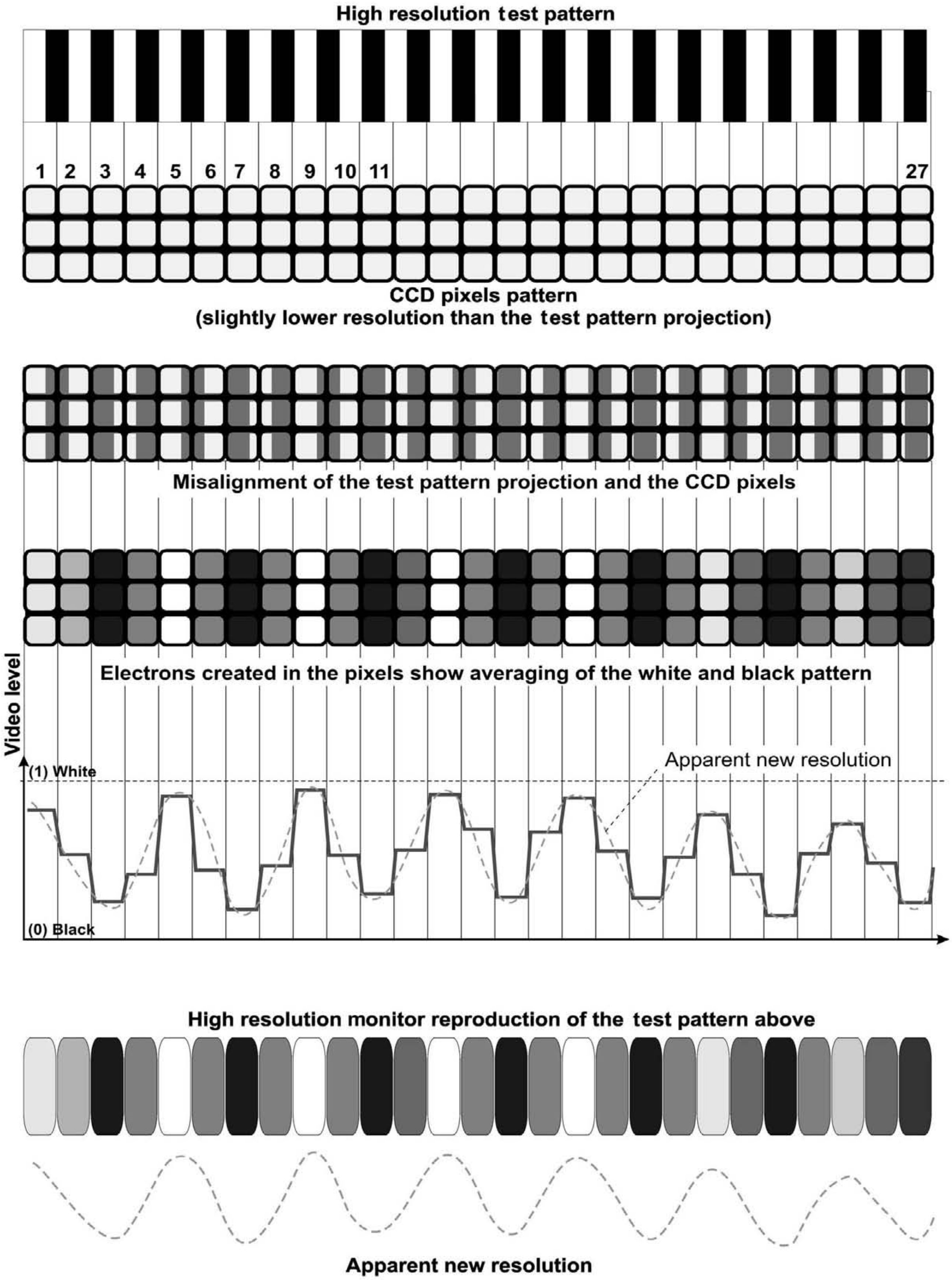
There is, however, an unwanted by-product of the CCD sampling. This is the well-known ***Moiré pattern*** that occurs when taking shots of higher-resolution objects. This is usually obvious with, for example, a news reader wearing a coat or shirt with a very fine pattern. This can mathematically be described as a foldover frequency around the sampling one. Since the spatial sampling frequency should be twice

the highest frequency in the optical image F_{smax}, we can represent it, in the frequency domain, with a single frequency located at the Nyquist frequency $F_{NYQUIST}$. The basic bandwidth spatial spectrum of the optical signal will be modulated around this frequency, very similar to an amplitude modulation side bands spectrum. If a high spatial frequency exists in the optical image projected on the CCD chip, and if this frequency is higher than half of the $F_{NYQUIST}$ frequency, the side bands (after the sampling is done) will fold over into the visible basic bandwidth and we will see the result as an unwanted pattern, known as the Moiré pattern. The Moiré frequency is lower than the highest frequency of the camera ($F_{NYQUIST}/2 - F_{smax}$).

To minimize this unwanted effect, ***low-pass optical (LPO) filtering*** has to be done. These filters are usually part of the CCD chip glass mask and are formed by combining several birefringent quartz plates. The effect is similar to blurring the fine details of an optical image.



CCD chip as a sampler


High resolution test pattern
1 2 3 4 5 6 7 8 9 10 11 27
CCD pixels pattern
(slightly lower resolution than the test pattern projection)
Misalignment of the test pattern projection and the CCD pixels
Electrons created in the pixels show averaging of the white and black pattern
Video level
(1) White
(0) Black
Apparent new resolution
High resolution monitor reproduction of the test pattern above
Apparent new resolution

Correlated double sampling (CDS)

The noise in a CCD chip has several sources. The most significant is the thermally generated noise, but a considerable amount can be generated by the impurities of the semiconductors and the quality of manufacture.

High noise reduces the image sensor's dynamic range, which in turn degrades image quality.

A careful CCD device design and fabrication can minimize the noise. Also, low operating temperature can reduce thermally generated noise. Unfortunately, the user rarely has control over these parameters.

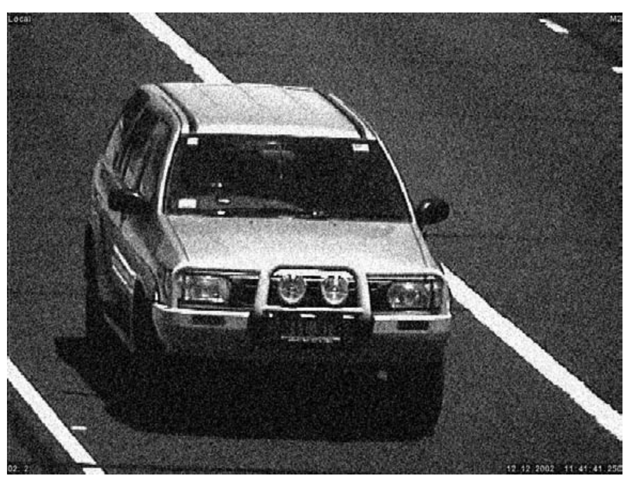
There is, however, a signal processing technique that can be implemented in the design of the CCD camera that reduces this noise considerably. This technique is called ***correlated double sampling (CDS)*****.** The term ***sampling*** here refers to the CCD signal output sampling.

The concept of CDS is based on the fact that the same noise component is present in the valid video as in the reference signal in between charge transfers. When the output stage of the CCD chip transfers packets of electrons, they are converted to an output voltage. To do this, CCD devices typically use a floating sensing diffusion to collect signal electrons as they are shifted out of the chip. As the electrons are transferred out of the CCD, the voltage on the sensing diffusion area drops. This voltage represents the valid data and is amplified on-chip by a thermally compensated amplifier. Before the next packet of signal electrons can be transferred into the diffusion area, it must be cleared from the previous packet. This represents a reference reset signal that has a thermal noise component of the same type. By extracting these two values, a less noisy signal is obtained.

CDS is best accomplished using two high-speed sample and hold circuits connected to the image sensor's output signal through a low-pass filter.

We will not go into more details on how these circuits are designed, as it is beyond the scope of this book, but it should be remembered that the CDS circuits are part of the camera electronics and not of the CCD chip.





Correlated double sampling is one method to reduce the CCD chip noise.

Camera specifications and their meanings

The basic objective of the television camera is, as already explained, to capture images, break them up into a series of still frames and lines, then transmit and display them onto a screen rapidly so that the human eye perceives them as motion pictures.

We should take a number of characteristics into account when choosing a camera. Some of them are important, others not so much, depending on the application.

It is impossible to judge a camera on the basis of only one or two characteristics from a brochure.

Different manufacturers use different criteria and evaluation methods, and in most cases, even if we know how to interpret all of the numbers from a specification sheet, we still have to evaluate the picture ourselves, relative to the picture taken with another camera.

Comparison tests are quite often the best and probably the only objective way to check camera performance, such as smear, noise, and sensitivity.

Do not forget: the general impression of a good quality picture is a combination of many attributes – resolution, smear, sensitivity, noise, gamma, and so on.

The human eye is not equally sensitive to all of these factors.

People with no experience would be amazed to find that a 50-line difference in resolution is sometimes of less importance to picture quality than a correct gamma setting or a 3-dB difference in the S/N figure, for example.

We will go through some of the most important features:

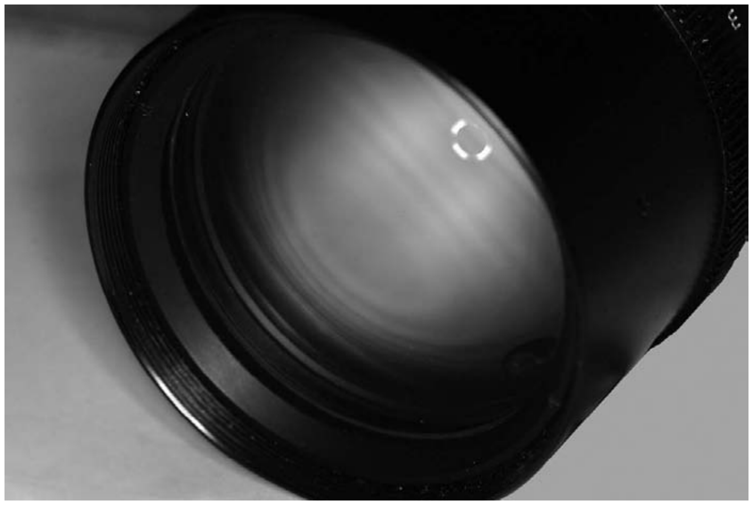
- Camera sensitivity
- Minimum illumination
- Camera resolution
- S/N ratio
- Dynamic range

Other, less important, but not wholly insignificant, features include gamma settings, dark current, spectral response, optical low-pass filtering, AGC range in dB, power consumption, and physical size.

Sensitivity

The ***sensitivity*** of a camera, though clearly defined in broadcast TV, is quite often misunderstood in CCTV and is usually confused with minimum illumination.

Sensitivity is represented by the minimum iris opening (maximum F-stop) that produces a *full* 1V$_{pp}$ (1 V peak-to-peak) video signal of a test chart, when that same test chart is lit by exactly 2000 lx at 3200° K color temperature of the source. The test chart has to have a gray scale with tones from black to white, and an overall reflection coefficient of 90% for the white portion of the gray scale.

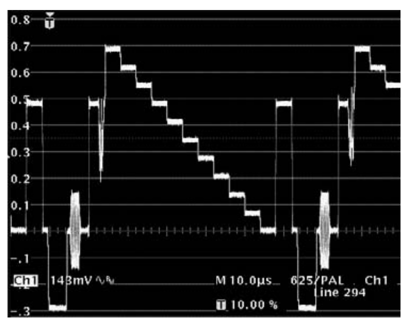


One of the standard test charts used for such purposes is the EIA gray scale chart. The white peak level needs to be 700 mV and the pedestal level around 20 mV. Gamma also plays a role in the proper reproduction of the grays and needs to be set at 0.45. In order to establish the sensitivity of the camera, a manual iris lens, usually of 25 to 50 mm, is required. In order to get a realistic measurement, the camera's AGC should be switched off.

When all of the above is done, the manual iris lens is closed just until the white peak level drops from 700 mV, relative to the blanking level. The reading obtained from the lens's iris setting, like F-4 or F-5.6, represents the camera sensitivity. The higher the number is, the more sensitive the camera is. It is important to consider using the same light source and gray scale chart when comparing different cameras.







Measurement and screen captures courtesy of Les Simmonds

The example above illustrates a camera sensitivity of F-5.6 for a gray scale test chart signal reproduced as full 1 V$_{PP}$ video.

Minimum illumination

A camera's ***minimum illumination***, contrary to the sensitivity, is not clearly defined in CCTV. It usually refers to **the lowest possible light at the object at which a chosen camera gives a recognizable video signal**. It is therefore expressed with luxes at the object, at which such a signal is obtained. The term ***recognizable*** is very loosely used, and depending on the manufacturer, it may or may not be defined. This represents one of the biggest loopholes in CCTV. Most manufacturers do not specify what video level we should get at the camera output for the light amount specified as the minimum illumination. This level could be 30% (of the 700 mV), sometimes 50%, and, for some, even 10% might be acceptable.

The usual wording when describing minimum illumination would be, for example: "0.1 lx at the object with 80% reflectivity using an F-1.4 lens."

Have in mind, however, that with high AGC circuitry in the camera, even 10% of video (70 mV) could be pumped up to appear as a much higher value than what it really is. This could obviously be misleading.

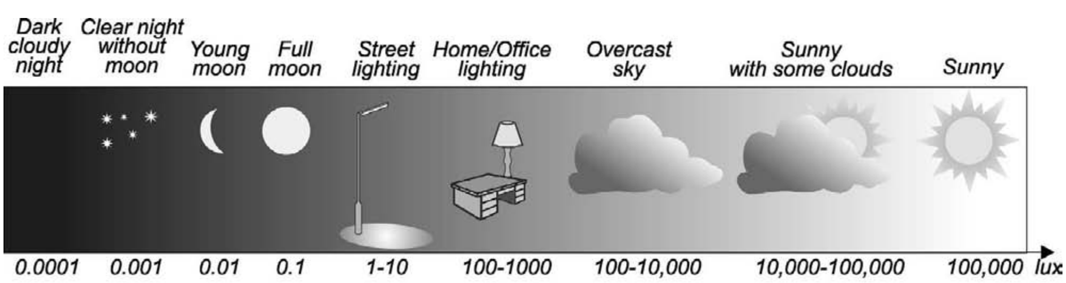
Let us say, for example, we have specifications that say 0.01 lx at the object with an F-1.4 lens, which presumes (but does not tell you) the AGC is switched to on. Another manufacturer may be very modest in its specs, stating, let us say, minimum illumination (where 50% of the video signal is obtained with the AGC set to off) of 0.1 lx with an F-1.4 lens. On paper, the first case would seem to be a much more promising camera than the second one, although the second, in reality, is much better.

Another matter for discussion is when some manufacturers state the minimum illumination at the object, while others may refer to the minimum illumination at the CCD chip itself. This is not the same, and there is a big difference as well.

When the minimum illumination of a camera (with the illumination at the object) is stated, we should also read to what F-stop it applies. Also, another important factor to know is the reflectivity percentage of the object when the illumination is stated.

If the minimum illumination is stated at the CCD chip, then not all the factors (such as reflectance and lens transmittance) have been taken into account. So, we have to compensate for all those factors when calculating the equivalent object illumination that is projected onto a CCD chip.

There is a rule of thumb (which I have elaborated on in the "Light onto an imaging device" section in Chapter 2) that, with an F-1.4 lens, the minimum illumination at the chip is usually 10 times higher



Some typical levels of illumination

(lower lux number) than the sensitivity at the object. For example, an illumination of 1 lx at the object with a reflectivity of 75% @ F-1.4 is equal to 0.1 lx illumination at the CCD chip.

As it can be concluded from the above, the real characteristics of a camera can be obscured quite easily by simply not stating all of the factors. **Read the specs carefully**.

A known fact is that B/W CCD cameras always have a much lower minimum illumination than color CCD cameras.

One reason for this is the infrared cut filter on the CCD chip. As described earlier, it corrects the spectral response of the CCD chip so that it can be closer to the human eye's sensitivity, but it also reduces the amount of light that falls on the chip.

The other reason is the primary color construction of a single color chip, as used in CCTV. A single pixel of a color CCD chip is composed of three subpixels, sharing the same physical space of a single B/W pixel. The size will be no more than one-third of a B/W pixel, indirectly reducing the sensitivity.

In the period between the previous edition of this book and this one, many CCD cameras have appeared called Day/Night cameras. These cameras usually have a color chip that is converted into B/W by removing the infrared filter mechanically and integrating the RGB pixels into one monochrome signal. This has an effect of a more sensitive but monochrome camera for low light levels. This also extends the infrared spectrum response of the camera (since the infrared cut filter is removed). Some cameras only switch to monochrome mode without removing the infra-red cut filter and integrating the RGB pixel response. Some manufacturers have gone an extra step by putting physically two separate chips, one color and the other monochrome, and then use some kind of mechanical switching between the two, when the light level drops below a certain level.

Although such designs are very practical, the mechanical switching design has to be extremely good as it might eventually fail if it is executed every day. The most common application of these cameras would be in areas where nighttime viewing with infrared light is required while preserving the color operation at full daylight.

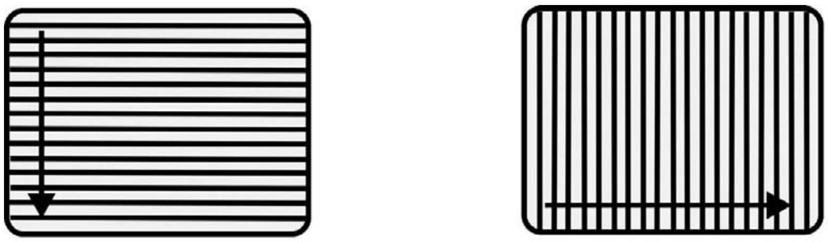
The majority of color cameras these days, even without removing the infrared cut filter, have better sensitivity than the human eye.



The example above shows a boy with a candle in his hand on the left-hand side, hardly noticeable by the film camera, while the CCTV camera sees it quite nicely as shown on the monitor right.

Camera resolution

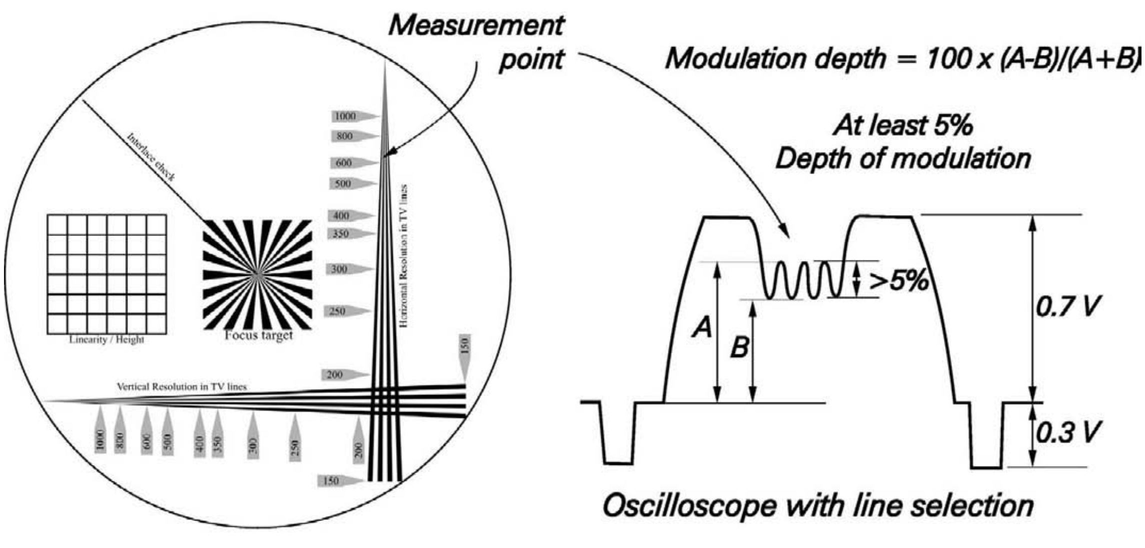
Camera resolution is very simple but quite often misunderstood. It is also one of the most frequently quoted parameters of a camera or complete system. When talking about resolution of a complete system (camera-transmission-recording-monitor), the most important part is the input (i.e., the camera resolution). There are vertical and horizontal resolution, and they are measured using a test chart.



Vertical resolution on the left and horizontal on the right

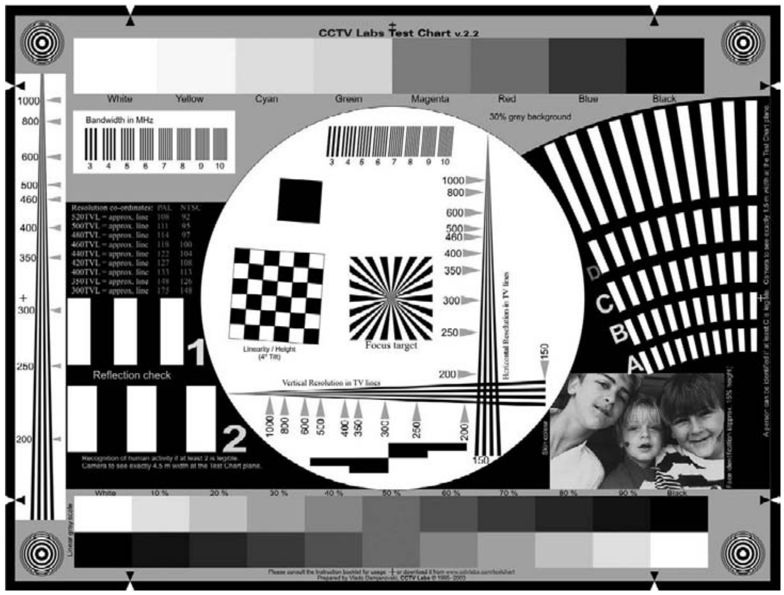
Vertical resolution is the maximum number of horizontal lines that a camera is capable of resolving. This number is limited to 625 horizontal lines by the CCIR/PAL standard, and to 525 by the EIA/NTSC recommendations. The real vertical resolution (in both cases), however, is far from these numbers. If we take into account the vertical sync pulses, equalization lines, and so on, the maximum for vertical resolution appears to be 576 lines for CCIR/PAL and 480 for EIA/NTSC. This needs to be further corrected by the Kell factor of 0.7, to get the maximum realistic **vertical resolution** of 400 TV lines for CCIR/PAL (see "Resolution" in Chapter 4, "General characteristics of television systems" for more in-depth study), similar deduction can be applied to the EIA/NTSC signal, where the maximum realistic vertical resolution is 330 TV lines.

Horizontal resolution is the maximum number of vertical lines that a camera is capable of resolving. This number is limited only by the technology and the monitor quality. These days, we have CCD cameras with horizontal resolution of more than 600 TV lines. The horizontal resolution of CCD



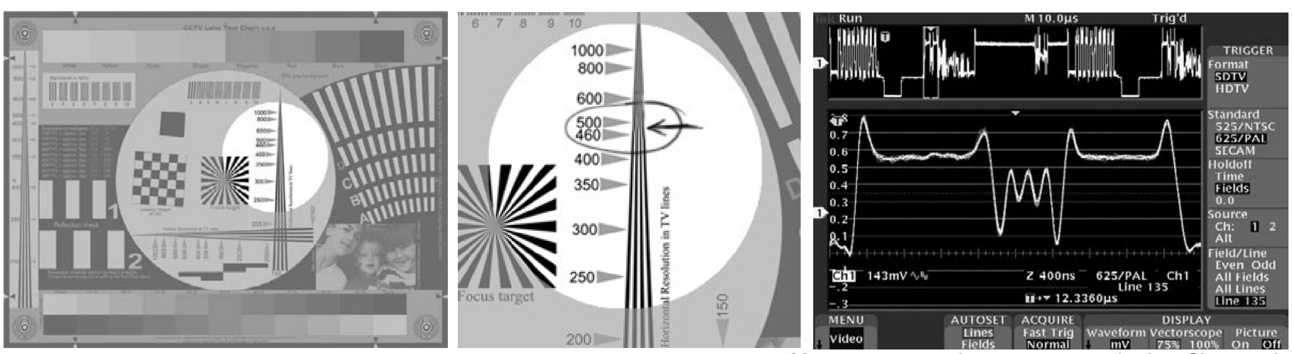
More accurate horizontal resolution measurement with 5% modulation depth

cameras is usually 75% of the number of horizontal pixels on the CCD chip. As explained earlier, this is a result of the 4:3 aspect ratio. When counting vertical lines in order to determine horizontal resolution, we count only the horizontal width equivalent to the vertical height of the monitor. The idea behind this is to have equal thickness of lines, both vertically and horizontally. So if we count the total number of vertical lines across the width of the monitor, we then have to multiply this by 3/4, which is equal to 0.75. Because this is an unusual counting, **we always refer to horizontal resolution as TV lines (TVL) and not just lines**.



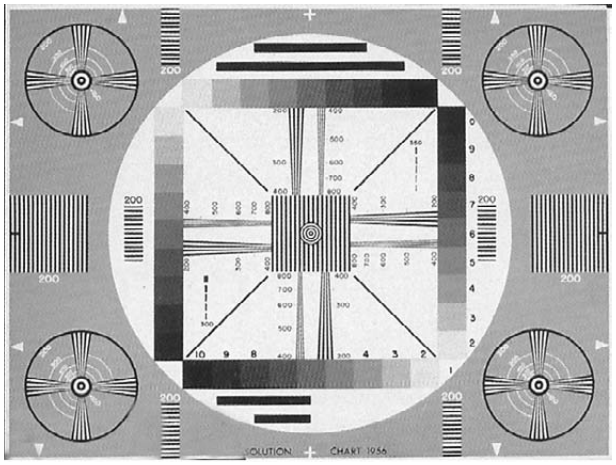
The CCTV Labs test chart is specially designed for CCTV and is used to check resolution and many other important details.

The important thing to observe, when measuring the resolution, is that the video signal must be properly terminated with 75 Ω and the image must be seen in full, without the picture being overscanned (as is the case with most standard monitors). To do this, a high-resolution monitor with higher resolution than the camera under test and with an underscanning feature needs to be used. The camera is then set to the best focus possible (usually at a middle F-stop, 5.6 or 8), having the test chart fully in the field of view. Also, all internal camera correcting circuits (AGC, gamma, CCD-iris) need to be switched off. **Resolution can then be visually checked by measuring where the resolution lines (in the form of a sharp triangle) merge into smaller number**. For example, if the test chart shows four lines as in the example below, the point where these merge into three, or two, is the limit. For most accurate measurement, only the luminance signal should be analyzed, typically by turning the color completely down, or even better using Y/C connection on the camera, if such is available. Since the merging of these lines does not have a clean cut, it represents only an approximate conclusion. The visual error of reading might be around 10%, which makes it very difficult to observe a difference between cameras with close resolution, for example 460 TVL and 480 TVL. For a more precise reading, a high-quality oscilloscope, with TV line selection feature, should

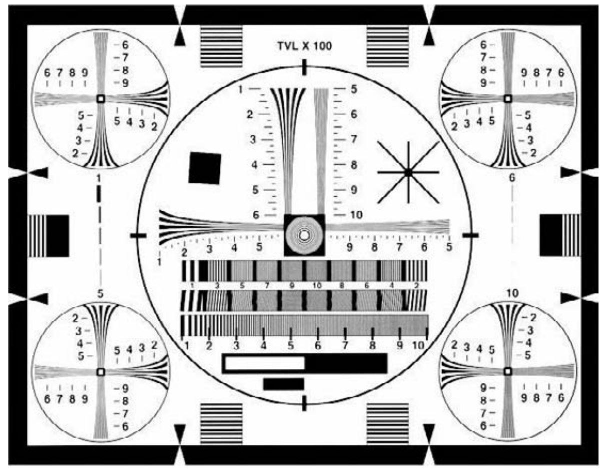


Measurement and screen capture by Les Simmonds

Visual detection of a horizontal resolution (in the middle) is not as precise as when using a proper oscilloscope with line selection and measuring 5% modulation.

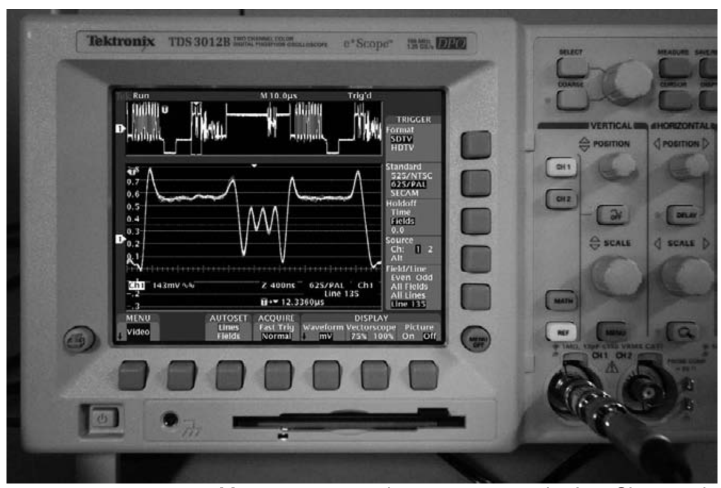


RETMA test chart



The IEEE-208 is a new recommendation for resolution measurement.

be used. The measurement is then narrowed down to selecting a line where the four lines modulation depth is equal or better than 5%. How this is calculated is shown on the drawing on the previous page and is basically $100 \times (A - B)/(A + B)$, where A is the highest point and B the lowest of the measured lines. Using an oscilloscope in such a case enables us to disregard the monitor's resolution limits. In order to know which part of the test chart you are measuring, you should have a way of telling which line you are measuring on the test chart. There are oscilloscopes such as the one shown in the photo, which can switch to a picture display, and the measured point is indicated with a line. If this is not the case with your instrument, you need to somehow mark the position so that you can recognize it on the oscilloscope waveform reading. In the case of the CCTV Labs test chart, we have made this even easier by having a line indicator on the left-hand side of the text chart.



Measurement and screen capture by Les Simmonds

Highly recommended – the Tektronix TDS3012B

It should also be noted that only good optics need be used when measuring resolution; otherwise average lenses tend to have better center resolution and the corners of an image (center is always better than the corners), so with such lenses resolution measurements are best if made in the central area of the test.

Resolution is closely related to the signal bandwidth a camera is capable of reproducing. Their correlation was explained in the earlier section on resolution, but a simple rule of thumb is that 80 TVL (TV lines) are equal to 1 MHz of bandwidth.

Practical experience shows that the human eye can hardly distinguish a resolution difference of less than 50 lines. This is not to say that the resolution is not an important factor in determining camera quality, but small resolution differences are often hardly noticeable, especially if the resolution difference is smaller than 10% of the total number of pixels.

Single-chip color CCD cameras (as used in CCTV) have lower resolution than B/W, again because of the separation into three color components, yet they still have the same size chips as B/W cameras. When analog signal is converted into digital, other factors need to be taken into account. You will find more explanation of this in Chapter 9. Three-chip color cameras, as used in broadcast TV, have higher resolution. Also, high-definition TV cameras are now available (unfortunately we do not use these in CCTV yet), where horizontal resolution exceeds 1000 TV lines.

A number of test charts now on the market can be used to evaluate cameras resolution. The most well-known was the EIA RETMA chart, but a new one devised by the IEEE-208 recommendation is getting more popular. There are others which you can easily find on the Internet. Many of them are designed to measure only one particular characteristic of a camera, but our own CCTV Labs test chart, which was designed specifically for the CCTV industry and introduced with the first edition of this book in 1995, has become a de facto CCTV industry standard.

Over 500 manufacturers are using the ***CCTV Labs*** test chart in their measurements and comparison tests. As with the previous editions of this book, we have enclosed a reproduction of this chart at the back of the book. This is the latest version, and with the evolution of versions throughout the years, each one has introduced more measurement details. For more accurate measurements we encourage the reader to obtain the larger format (A3) and more accurate reproduction chart available from the ***CCTV Labs*** web site (***www.cctvlabs.com***). This one has more accurate details and color reproduction. Our publisher has taken maximum care to correctly reproduce the version available in this book, but exactitude is beyond our control as the procedure encompasses color inks and printing machinery that could not have been taken into account in our chart setup.

Another approach that we encourage is the open exchange of test chart results and image captures for comparison purposes, all of which are available at the ***CCTV Labs*** web site. We welcome you to submit your results so that other readers can compare cameras and DVRs and analyze thir results.



Measuring bandwidth is closely related to resolution.

For more details on what else is measured with the ***CCTV Labs*** test chart, please refer to Chapter 14.

Signal/noise ratio (S/N)

The ***signal to noise (S/N)*** ratio is an expression that shows how good a camera signal can be, especially in lower light levels. **Noise cannot be avoided but only minimized**. **It depends mostly on the CCD chip quality, the electronics and the external electromagnetic influences, but also very much on the temperature of the electronics.** The camera's metal enclosure offers significant protection from external electromagnetic influences. Internal noise sources include both passive and active components of the camera, their quality and circuit design; noise depends very much on the temperature. This is why, when stating the S/N ratio, a camera manufacturer should indicate the temperature at which this measurement is taken.

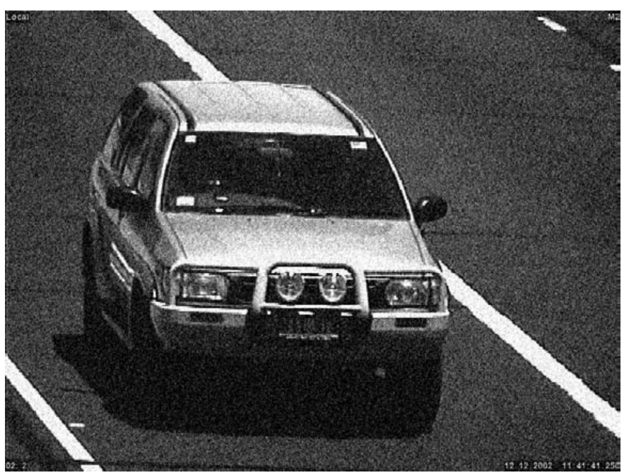
The image noise is very similar to the noise in old audio tapes, only it is part of a video and not of an audio signal. On the screen, a noisy picture appears grainy or snowy, and if color signal is viewed, sparkles of colors may be noticeable. Extremely noisy signals may be difficult for equipment to synchronize these days, with the increased usage of digital video recorders. Noisy pictures when captured and digitized look even worse because compression engines see the noise speckles as video detail.

The units for expressing ratios (including the S/N) are called *decibels* and are written as dB.

Decibels are only relative units. Instead of expressing the ratio as an absolute number, a logarithm is calculated. The reasoning behind this is simple: logarithms can show big ratios as only two- or three-digit numbers, but more importantly, signal manipulation (as when calculating the attenuation of a medium or amplification of a system) is reduced to simple addition and subtraction. Another reason for using decibels (i.e., logarithms) is the more natural understanding of sound and vision quantities. Namely, the human ear, as well as the eye, hears and sees sound and light quantities (respectively) by obeying logarithmic laws.

When a ratio of any two numbers with the same units is calculated, the units are in dB only. If, however, a relative ratio is calculated – for example, a voltage level relative to 1 mV – the units are called **dBmV**. If the power value is shown relative to 1 μW, the units are called **dBμW**.





Seeing details in an image is affected not only by the resolution but by the noise also.

The general formula for voltage and current ratios is:

$$S/N = 20 \log(V_s/V_n) \quad (41)$$

where: V_s is the signal voltage and V_n is the noise voltage. Current values are used when a current ratio needs to be shown.

If a power ratio is the purpose of a comparison, the formula is a little bit different:

$$S/N = 10 \log(P_1/P_2) \quad (42)$$

We will not explain here why this is different (the factors 10 and 20 in front of the logarithm), but remember that it comes from the relation between the voltage, current, and power.

In CCTV, we use decibels mostly for calculating voltage ratios, which means the first formula will be the one we would use.

The following table gives some dB values of voltage (current) and power ratios. Please note the difference between the two. While a 3 dB voltage difference means only a 41% higher value of the compared volts relative to the referred one, in terms of power this 3 dB means twice as much power (100% increase) of the compared relative to the reference power.

dB	0	0.1	0.2	0.3	1	2	3	10	20	30	60
Voltage/current ratio	1	1.012	1.023	1.035	1.122	1.259	1.413	3.162	10	31.62	1000
Power ratio	1	1.023	1.047	1.072	1.259	1.585	1.995	10	100	1000	1,000,000

Decibels table

The S/N ratio of a CCD camera is measured differently from that of a broadcast or transmitted signal.

In a broadcast TV signal the S/N ratio is the signal versus the accumulated noise from the transmission to the reception end. This is defined as the ratio (in dB) of the luminance bar amplitude to the RMS voltage of the superimposed random noise measured over a bandwidth of frequencies between 10 kHz and 5 MHz. There are special instruments that are designed to measure this value directly from the signal, by using some of the video insertion test signal (VITS) lines.

The S/N ratio in a CCD camera is defined as the ratio between the signal and the noise produced by the chip combined with the camera electronics. In order to get a realistic value for the S/N ratio of a camera, all internal circuits that modify the signal in one way or another need to be switched off or disabled. This includes gamma, AGC, CCD-iris, and backlight compensation circuitry. The temperature, as already mentioned, should be kept at room level. Of the few different methods used to measure camera video noise, the easiest one is to use a special instrument called a ***video noise meter***. This unit selects the noise in the band between 100 kHz and 5 MHz and reads the S/N directly in decibels.

Practically, a S/N ratio of more than 48 dB is considered good for a CCTV CCD camera.

Do not forget: a 3 dB higher S/N ratio means approximately 30% less noise, since the video level does not change. So when comparing a 48 dB camera with a 51 dB camera, for example, the latter one will show a considerably better picture, more noticeable at lower light levels. We should always assume that the automatic gain control (AGC) is off when stating S/N ratios. For comparison purposes, let us just mention that broadcast CCD cameras have a ratio of more than 56 dB, which is extremely good for an analog video signal.



Photo courtesy of Cohu

A camera design with Peltier cooling keeps the CCD chip operating temperature at 5ºC and reduces the noise by 85%.

Keeping the camera as cool as possible reduces the noise. Lower temperatures, in any electronic device, produce less noise. In astronomy and other industrial applications there are specially cooled cameras designed to keep the CCD as cool as possible. Temperatures of below –50° C are not uncommon. For such applications, cameras are available where the CCD block has provision for a coolant to be attached to it. Some designs, like the one shown on the photo above, use Peltier cooling to keep the CCD chip always at 5º C, which reduces the noise to one-eighth of the normal room temperature. So, it should be remembered, if in a CCTV system we do not use good quality cameras, high temperature can play a significant role in lowering the picture quality.

Dynamic range of a CCD chip

Dynamic range (DR) is seldom mentioned in CCTV camera specification sheets. Nonetheless, it is a very important detail of the camera performance profile.

The dynamic range of a CCD chip is defined as the maximum signal charge (saturation exposure) divided by the total RMS (root-mean-square) noise equivalent exposure. DR is similar to S/N ratio, but it only refers to the CCD chip dynamics when handling low to bright objects in one scene. While the S/N ratio refers to the complete signal including the camera electronics and is expressed in dB, the DR is a pure ratio number (i.e., not a logarithm).

This number actually shows the light range a CCD chip can handle – only this light range is not expressed with the photometric units but with the generated electrical signal. It starts from the very low light levels, equal to the CCD chip RMS noise, and goes up to the saturation levels. Since this is a ratio of two voltage values, it is a pure number, usually in the order of thousands. Typical values are between 1000 and 100,000. External daylight can easily saturate the CCD chip since the dynamic range of the light variation in an outdoor environment is much wider than the range a CCD chip can handle. A bright sunny day, for example, can easily saturate a CCD chip, especially if a camera does not have AGC, an auto iris lens, or a CCD-iris function. An auto iris lens optically blocks the excessive light and reduces it to whatever upper level the CCD chip can handle, whereas CCD-iris does that by electronically

reducing the exposure time of the chip (1/50 s for CCIR/PAL, 1/60 s for EIA/NTSC).



On the left a camera with visible smear and on the right almost invisible smear

When saturation levels are reached during a CCD exposure (1/50 s for PAL, or 1/60 s for NTSC), the ***blooming*** effect may become apparent when excessive light saturates not only the picture elements (pixels) on which it falls but the adjacent ones as well. As a result, the camera reduces the resolution and detail information of the bright areas. To solve this problem, a special **antiblooming** section is designed in most CCD chips. This section limits the amount of charges that can be collected in any pixel. When antiblooming is designed properly, no pixel can accumulate more charges than what the shift registers can transfer. So, **even if the dynamic range of such a signal is limited, no details are lost in the bright areas of the image**. This may be extremely important in difficult lighting conditions such as looking at car headlights or perhaps looking at people in a hallway against light in the background.

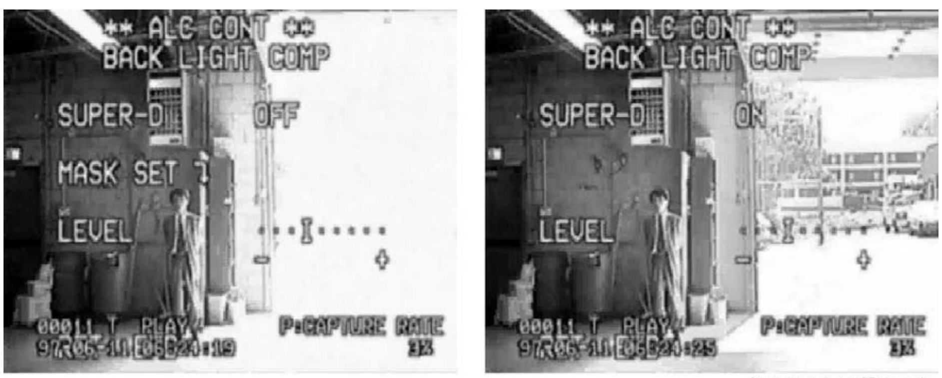
Some camera makers, like Plettac, have introduced a special design that blocks the oversaturated areas during the digital signal processing stage. The video signal AGC circuitry then does not see extremely bright areas as a white peak reference point, but much lower levels are taken as white peaks, thus making the details in the dark more recognizable.



Photo courtesy of Plettac Electronics

Peak light blanking by Plettac

Others are using new methods of CCD chip operation, where, instead of having one field exposure every field time (1/50 s for PAL, or 1/60 s for NTSC), two exposures are done during this period. One at a very short time, usually around 1/1000 s and the other at the normal time that will depend on the amount of light. Then, the two exposures are combined in one field so that bright areas are exposed with short exposure duration giving details in the very bright areas, and the darker areas are exposed with the lower speed giving details in the dimmer part of the same picture. The overall effect is of the dynamic range of the camera being increased a number of times. Some manufacturers call this the "***superdynamic effect***."

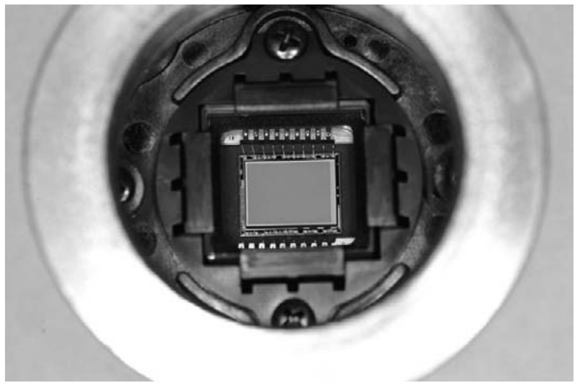


Images courtesy of Panasonic

The Panasonic superdynamic effect

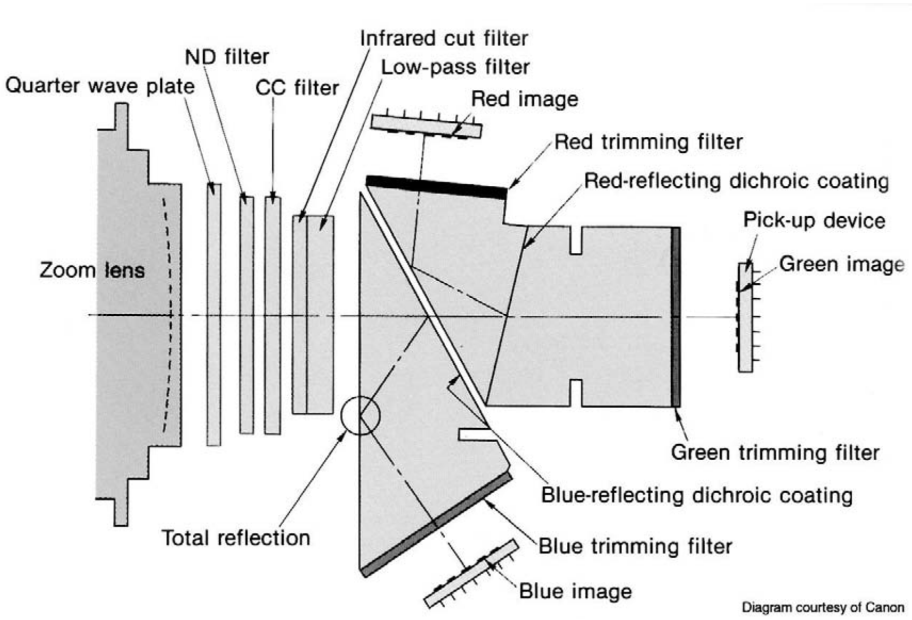
Color CCD cameras

Color television is a very complex science in itself. The basic concept of producing colors in television is, as described earlier, by combining the three primary colors: red, green, and blue. The color mixing actually happens in our eyes when we view the monitor screen from a certain distance. The discrete colors (R, G, and B) are so small that we actually see a resultant color produced by the additive mixing of the three components. As mentioned earlier, this is called ***additive mixing***, as opposed to ***subtractive***, because by adding more colors we get more luminance, and with a correct mixture of the primary colors, a white can be obtained.



Single chip color CCD cameras are the most common in CCTV.

Most broadcast color TV cameras are made with three CCD chips, each of which receives its own color component. The white light's separation into R, G, and B components is done with a special ***optical split-prism***, which is installed between the lens and the CCD chips.



Three-chip CCD color cameras use split-prism for color separation.

The split-prism is a very expensive and precisely manufactured optical block with dichroic mirrors. These are called three-chip color cameras and are not very commonly used in CCTV because they are considerably more expensive than one-chip cameras. They do, however, offer a very high-resolution and superior technical performance.

In CCTV, single-chip color cameras are the most common. They produce a composite color video burst signal, known as CVBS. As already discussed under "Color video signal," in Chapter 4, the three components of the signal that are embedded in the CVBS composition are luminance (Y) and the

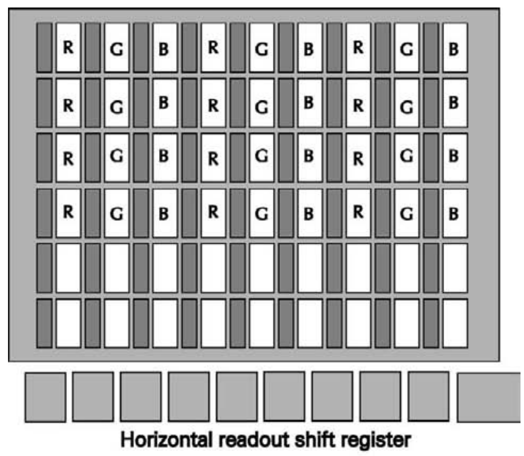
color difference for red ($V = R - Y$) and for Blue ($U = B - Y$). These are quadrature modulated and, together with the luminance, combined in a composite color video signal. Then, the color monitor circuit processes these components and obtains the pure R, G, and B signals.

In single-chip CCD color cameras, the colors may be separated using one of the two filtering methods:

- ***RGB stripe filter***, where three vertical pixel columns (stripes) are next to each other: red, green, and blue.

- ***Complementary colors mosaic filter***, where the CCD chip pixels are not made sensitive to R, G, and B colors, but to the complementary colors of cyan, magenta, yellow, and green, ordered in a mosaic.

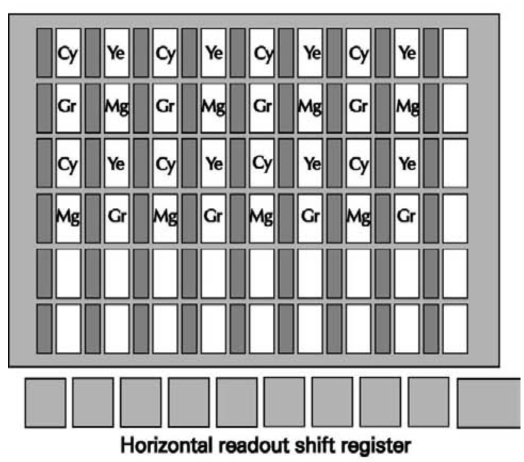
The first type of single-chip color CCD camera has a very good color reproduction and requires simpler circuits to achieve the same. However, it suffers from very low horizontal resolution, which is usually on the order of 50% of the total number of pixels in the horizontal direction of the chip. The vertical resolution, however, achieves the full number of vertical pixels. This type of color camera can easily produce RGB color signals.



RGB stripe filter of a single-color CCD chip

The mosaic-type single-chip color CCD camera requires more complex camera-electronics, and it may lag in color reproduction quality compared to the RGB models (because of the color transformation needed to be applied to the Cy, Mg, Ye, and Gr components), but it offers a much higher horizontal resolution of over 65% of the horizontal number of pixels.

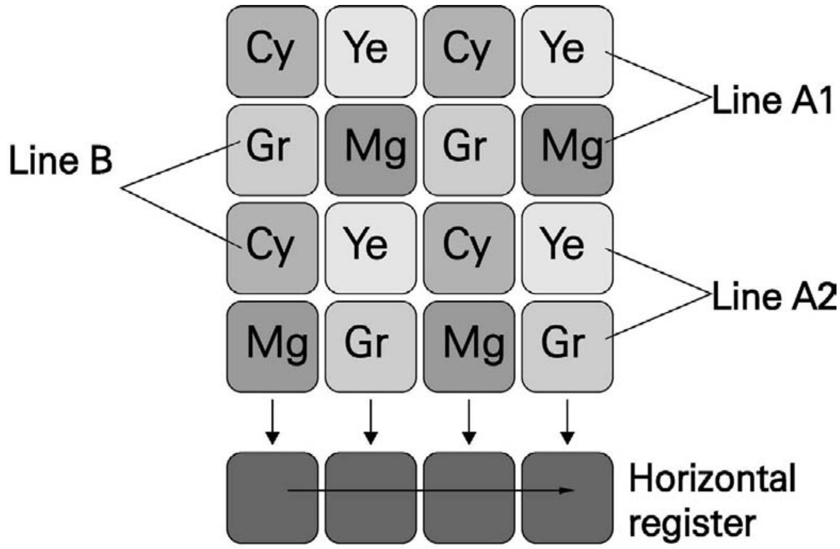
Since the mosaic type is the most common type of camera in CCTV, we will devote a bit more space to explaining how color components are converted to obtain a composite color video signal.



Complementary (Cy, Ye, Mg, Gr) mosaic filter of a single-color CCD chip

The mosaic filter, which is usually called ***color filter array*** (CFA), splits the light into magenta, cyan, yellow, and green components. As mentioned, these colors are selected as complementary colors. So, in practice, this type of single-chip CCD color camera uses Mg, Cy, Ye, and Gr color components to produce the luminance signal Y, and the color differences $V = R - Y$ and $U = B - Y$. It should be noted that the single-chip color CCD cameras have light-sensitive pixels of the same silicon structure, and are not different for different colors as some may think. It is the CFA filter that splits the image into color components.

In order to understand how this is produced, see the diagram of the color filter array on the right.



Color filter array (CFA) of a color, single-chip, CCD camera

This type of CFA refers to a standard field integration camera, that is, a camera where the exposure time is 1/50 s for PAL or 1/60 s for NTSC. As can be seen from the diagram, the four cells of the horizontal shift register contain signals of (Gr + Cy), (Mg + Ye), (Gr + Cy) and (Mg + Ye), respectively. By proper processing of these four signals, we can get the three components that make a composite color video signal: the luminance (Y), the red color difference (R - Y), and the blue color difference (B - Y).

First, the luminance signal is obtained by the relation:

$$Y = ½ [(\mathrm{Gr} + \mathrm{Cy}) + (\mathrm{Mg} + \mathrm{Ye})] = ½ (2\mathrm{B} + 3\mathrm{G} + 2\mathrm{R}) \qquad (43)$$

The above relation shows how luminance signal is obtained in both types of single-chip color CCD cameras – the mosaic filter and RGB stripe filter.

The red color difference is similarly obtained through line A1:

$$R - Y = [(\mathrm{Mg} + \mathrm{Ye}) - (\mathrm{Gr} + \mathrm{Cy})] = (2\mathrm{R} - \mathrm{Gr}) \qquad (44)$$

The blue color difference is composed of line A2 values:

$$B - Y = [(\mathrm{Gr} + \mathrm{Ye}) - (\mathrm{Mg} + \mathrm{Cy})] = (2\mathrm{B} - \mathrm{Gr}) \qquad (45)$$

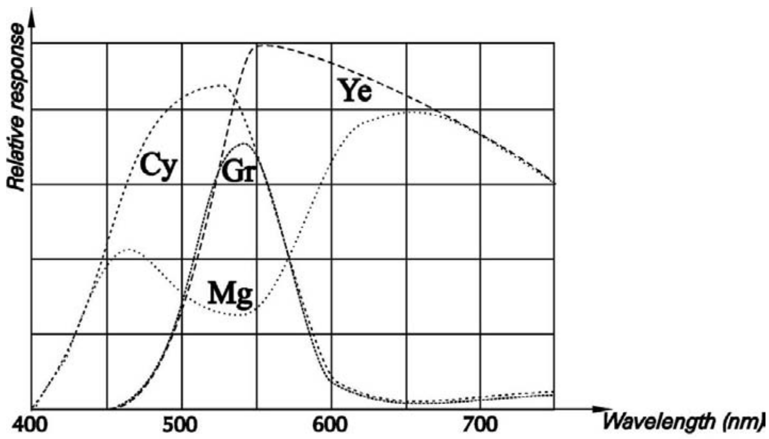
So, these are the two signals that, together with the luminance, are embedded in the composite video signal and represent a PAL (or NTSC) color video signal, as per standards.

New developments are continually improving the CCD (and the new CMOS) imaging technology, and one of them is worth mentioning here. This is the multilayered single-chip color developed by Foveon Inc. Instead of having pixels for each primary color separately, they have invented a layering technique where colors are separated as they penetrate on the same pixels. The result is better color reproduction and higher resolution. Cameras with Foveon's X3 chip are already on the photographic market, and it will not be a surprise if similar cameras appear on CCTV cameras.

White balance

From color cameras we require, apart from the resolution and minimum illumination, a good and accurate color reproduction.

The first color CCD cameras had an external color sensor (usually installed on top of the camera) whose light measurement would influence the color processing of the camera. This was called ***automatic white balance* (AWB)**, but lacked precision owing to the discrepancy of the viewing angle between the white sensor and the camera lens. In modern cameras, we have a **through-the-lens** automatic white balance (TTL-AWB).



Spectral sensitivity of a color CCD chip camera with Cy-Mg-Gr-Ye mosaic CCD filter

Generally, the initial calibration of the camera is done by exposing the CCD chip to white on power up. This is achieved by putting a white piece of paper in front of the camera and then turning the camera on. This stores correction factors in the camera's memory, which are then used to modify all other colors. In a way, this depends very much on the color temperature of the light source in the area where the camera is mounted.

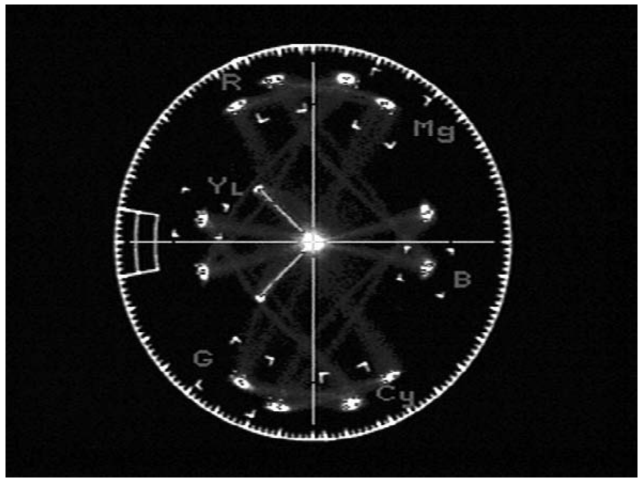


White balance setting usually can be automatic or manual.

Many cameras have an AWB reset button that does not require camera powering down. How good, or sophisticated, these corrections are depends on the CCD chip itself and the white balance circuit design.

Although the majority of cameras today have AWB, there are still models with *manual white balance* (MWB) adjustments. In MWB cameras there are usually two settings (switch selectable): indoor and outdoor. Indoor is usually set for a light source with a color temperature of around 2800° K to 3200° K, while the outdoor is usually around 5600° K to 6500° K. These correspond to average indoor and outdoor light situations. Some simpler cameras, however, may have potentiometers accessible from the

outside of the camera for continuous adjustment. Setting such a color balance might be tricky without a reference camera to look at the same scene. This gets especially complicated when a number of cameras are connected to a single switcher, quad, or multiplexer.



Accurate color reproduction can be checked with a vectorscope.

Newer design color cameras have, apart from the AWB, an ***automatic tracking white balance*** (ATWB), which continually adjusts (tracks) the color balance as the camera's position or light changes. This is especially practical for PTZ cameras and/or areas where there is a mix of natural and artificial light. In a CCTV system where pan and tilt head assemblies are used, it is possible while panning for a camera to come across areas with different color temperature lights, like an indoor tungsten light at one extreme and an outdoor natural light at the other. ATWB tracks the light source color temperature dynamically, that is, while the camera is panning. Thus, unless you are using ATWB color cameras, you have to be very wary of the lighting conditions at the camera viewing area, not only the intensity but the color temperature as well.

Last, and as mentioned earlier, do not forget to take into account the monitor screen's color temperature. The majority of color CRTs are rated as 6500° K, but some of them might have higher (9300° K) or even lower (5600° K) color temperature.

CMOS technology

CCD technology is about 30 years old now. It has matured to provide excellent image quality with low noise. Although CCD chip operational fundamentals are based on MOS electronics (metal-oxide-semiconductor), the actual manufacturing of CCD chips requires a special type of silicon technology with its own customized fabrication line.

It is technically feasible, but not economically so, to use the CCD process to integrate other camera functions, like the clock-drivers, timing logic, and signal processing. These are therefore normally implemented in secondary chips. Thus, most CCD cameras are comprised of several chips.

Apart from the need to integrate the other camera electronics into a separate chip, the Achilles heel of all CCDs is the clock requirement. The clock amplitude and shape are critical for successful operation. Generating correctly sized and shaped clocks is normally the function of a specialized clock-driver chip and leads to two major disadvantages: multiple nonstandard supply voltages and high power consumption. If the user is offered a simple single-voltage supply input, then several regulators will be employed internally to generate these supply requirements.

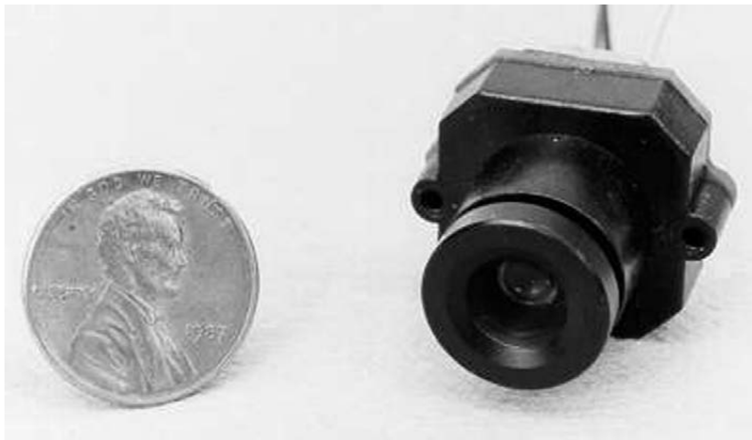


Photo courtesy of Marshall Electronics Inc.

A single-chip color CMOS camera

In the last couple of years a new type of image chip has appeared on the market called ***complentary metal oxide semiconductor*** (CMOS) chips.

CMOS sensors are manufactured on standard CMOS processes using the so-called very large scale integration (VLSI) technique. **This is a much cheaper and more standardized method of chip manufacturing than is the case with CCDs.**

A major advantage of CMOS cameras over CCDs lies in the high level of product integration that can be achieved through **implementing virtually all of the electronic camera's functions onto the same chip**. CMOS technology is ideal for this function, and with its timing logic, exposure control and A/D conversion can be put together with the sensor to make complete one-chip cameras.

CMOS imagers sense light in the same way as CCD, but from the point of sensing onward, everything is different. The charge packets are not transferred, but they are instead detected as early as possible by charge-sensing amplifiers, which are made from CMOS transistors. In some CMOS sensors, amplifiers are implemented at the top of each column of pixels – the pixels themselves contain just one transistor which is used as a charge gate, switching the contents of the pixel to the charge amplifiers. These passive pixel CMOS sensors operate like analog dynamic random access memory (DRAM).

Conceptually, the weak point of CMOS sensors is the problem of matching the multiple different amplifiers within each sensor. Some manufacturers have overcome this problem by reducing the residual level of fixed-pattern noise to insignificant proportions. With the initial CMOS designs and prototype cameras, there were problems with low-quality, noisy images that made the technology somewhat

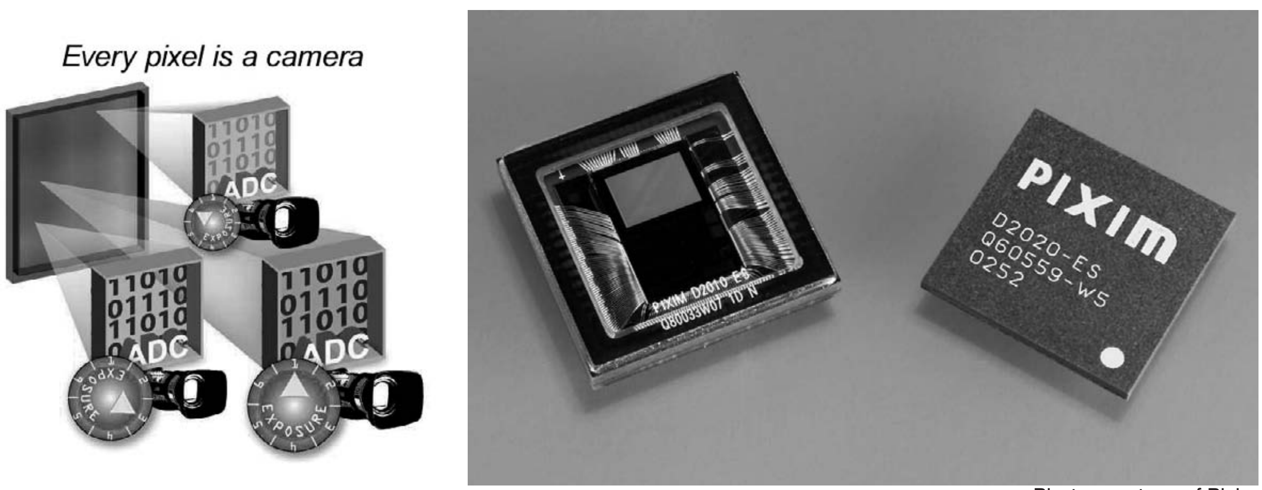


Photo courtesy of Pixim

Modern and sophisticated CMOS chip offers A/D conversion on the chip.

questionable for commercial applications. Chip process variations produce a slightly different response in each pixel, which shows up in the image as snow. In addition, the amount of chip area available to collect light is also smaller than that for CCDs, making these devices less sensitive to light.

These issues, however, have been improved considerably in the last five years. Many advancements in CMOS technology have occurred in the interval between the two editions of this book. The imaging obtained from CMOS chips has improved dramatically, driven by the explosive demand of digital cameras in photography; it forced manufacturers to find ways of increasing image quality while reducing the price of production. Some of the major CMOS manufacturers, such as Canon and Kodak, have introduced chips with 10 million pixels, which produce extremely good quality images. Many innovations and improvements in producing CMOS have been made. One such innovation is the removal of the so-called fixed pattern noise by method of imprinting the noise of the CMOS chip as its own "noise signature" and deducting it from an exposed image, thus producing a correction of the exposed image so that it appears with minimal noise.

Another new design that is especially interesting for CCTV is the one that we only hinted at as a possibility around five years ago, and it is now a reality. A company by the name of Pixim has developed a new CMOS chip that actually converts the analog electron charges into a digital stream of data, directly at the chip itself. This is a revolutionary and an extremely powerful new concept that allows for many imperfections of the CMOS and projected image to be improved or fixed. One of them is accurate control of light exposure which can vary at each pixel location, thus allowing even higher dynamic range; another one is subtracting the so-called dark noise of the chip itself, reducing the S/N of the chip.

Special low-light-intensified cameras

The CCD chips have better minimum illumination performance than the image tubes, but there is still a limit to how low they can see. A reasonably good approximation would be that a B/W CCD camera can see, in low light levels, as much as the human eye. Described in a technical way, normal B/W CCD cameras can cover a light range from 10^5 lx to 10^{-2} lx. This range of light intensity is called a ***photopic vision*** area.

Sometimes, for special purposes, there is a need for an even lower light level camera. The light range lower than 10^{-2} lx belongs to the ***scotopic vision*** area. Although the human eye cannot see this low, it is possible to get images from light levels much lower than 10^{-2} lx with the use of the integration function available on some cameras. This is a function where exposure time longer than 1/50 s (1/60 s for EIA) is used. Obviously, in such a case we lose the real-time effect and the camera actually becomes a kind of storage device. This might not be acceptable for viewing moving objects in low light levels, but it is a good alternative for viewing slow-moving objects in the dark. If we want to see real movement in the scotopic vision area, a special type of camera called ***intensified*****,** or ***low light level*** **(LLL),** can be used.

Intensified cameras have an additional element, called a ***light intensifier***, that is usually installed between the lens and the camera. The light intensifier is basically a tube that converts the very low

light, undetectable by the CCD chip, to a light level that can be seen by it. First, the lens projects the low light level image onto a special faceplate that acts as an electronic multiplying device, where literally every single photon of light information is amplified to a considerable signal size. The amplification is done by an ***avalanche*** effect of the electrons, which light photons produce when attracted to a high-voltage static field. The resultant electrons hit the phosphor coating at the end of the intensifier tube, causing the phosphor to glow, thus producing visible light (in the same manner as when an electron beam produces light onto a B/W CRT). This now visible image is then projected onto the CCD chip, and that is how a very low light level object is seen by the camera. Because of the very specific infrared wavelengths of low light levels, as well as the monochrome phosphor coating of the intensifier, the LLL cameras will only display monochrome images.



Photo courtesy of Pixel Vision

A different concept of low light level camera by back illumination

It is to be expected that, having a phosphor coating inside the intensifier, the lifetime, or more correctly, the MTBF (***mean time between failure***) of an intensifier tube is short. It is usually in the vicinity of a couple of thousand hours.

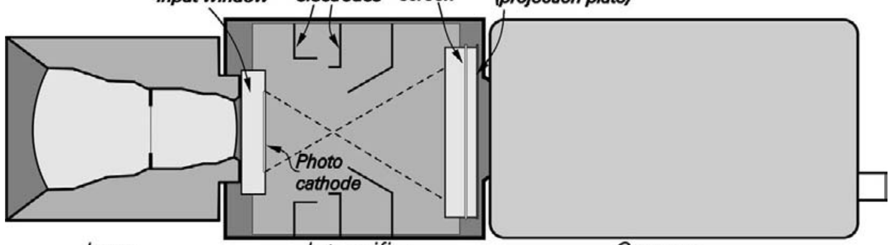
In order to prolong this lifetime, high F-stop lenses are necessary (with at least F-1200), especially if the camera is to be used day and night. Also, lenses with infrared light correction should be more adequate.

More advanced and purposely built LLL cameras have a fiber optic plate for coupling the phosphor screen of the intensifier tube to the CCD chip. This technique avoids any further light losses and improves picture sharpness.



Photo courtesy of Pulnix

An LLL camera



Low light level intensifier camera

Needless to say, the intensifier requires a power source in order to produce the high-voltage static field for the electrons' acceleration.

This type of intensifier can be bought separately and installed onto a camera, but specifically made integrated cameras have much better performance.



Photo courtesy of e2Vtechnologies

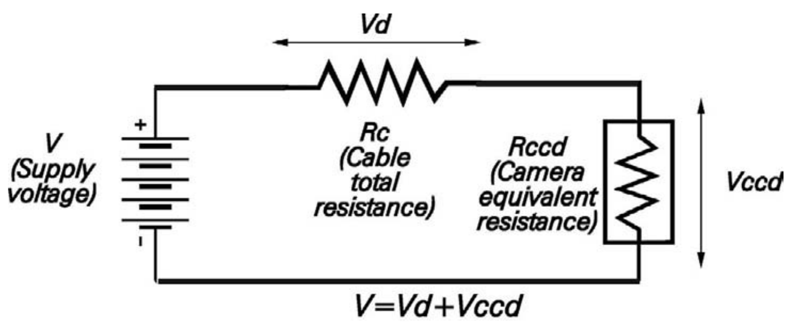
A modern LLL camera

Another interesting and innovative design has been offered by PixelVision Inc. with its back-illuminated CCD camera that operates without an image intensifier. This camera, the manufacturer claims, is capable of acquiring quality images at low light levels previously attainable only with image intensifier tubes. Conventional video cameras use front-illuminated CCDs that impose some limitations on performance. The design of their special device illuminates and collects a charge through the back surface, permitting the image photons to enter the CCD unobstructed, allowing for high-efficiency light detection in the visible and ultraviolet wavelengths. The manufacturer claims greater resolution under low light conditions through increased sensitivity, better target identification through superior contrast and resolution, lower cost, and a longer lifespan through increased reliability.

Camera power supplies and copper conductors

A typical CCD camera consumes between 3 and 4 W of energy. This means that a 12 V DC camera needs no more than 300 mA of current supply. A 24 V AC camera needs no more than 200 mA. As the technology improves, cameras will consume less current.

When powering a number of cameras from a central power supply, it is important to take the voltage drop into account and not to overload the supply.



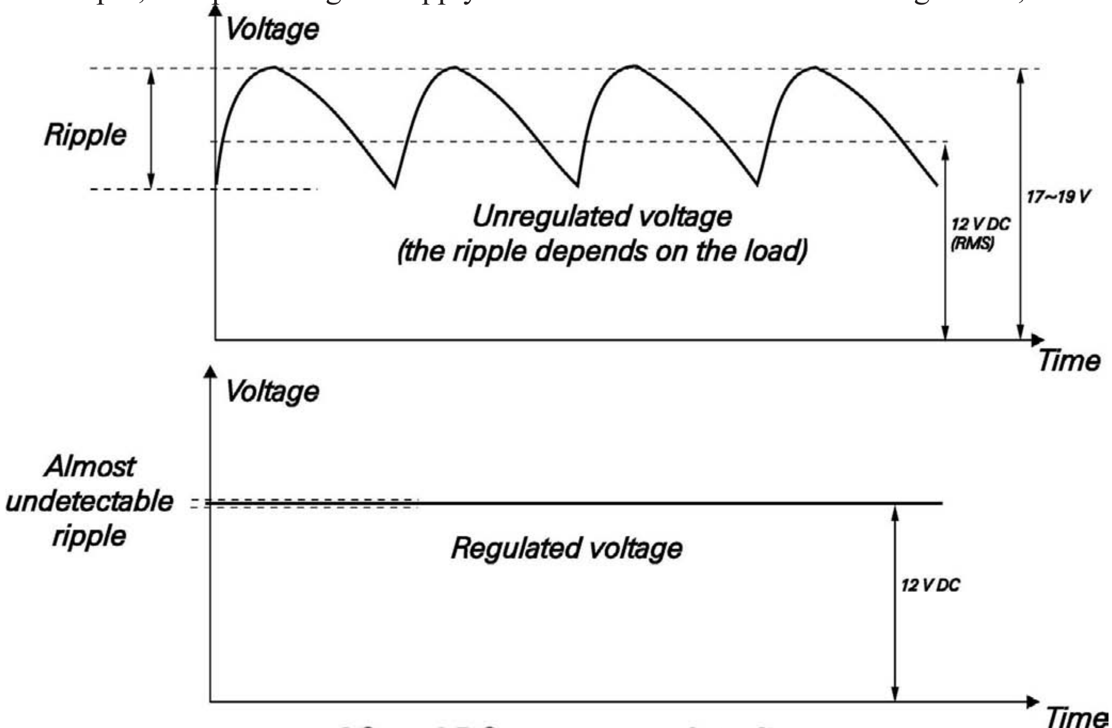
Voltage drop

Another very important factor to check with DC power supplies is whether or not they are regulated. For example, if a power supply of 12 V DC/2 A is used, it is advisable to have approximately 25% to 30% of spare capacity to minimize overheating. Be very critical when choosing a power supply. When some manufacturers quote 12 V/2 A, the 2 A may only be a maximum rating. This is usually defined with short lengths of peak deliveries. In other words, you cannot count on a constant load of 2 A with any 2 A supply. It really depends on the make and model. Very often, 12 V DC power supplies are actually made with a 13.8 V output used for charging batteries on security panels. Take this fact into account to minimize camera overheating, especially if there is only a short-run power cable between the camera and the power supply. Usually no intervention is required for a couple of hundred meters of power cable run because of the voltage drop, but if the camera is in the vicinity of the power supply, the excessive power must be dissipated somewhere, and this is usually in the camera itself. To put it simply, the 12 V DC camera gets hotter if it is powered from a 13.8 V rather than a 12 V power supply, and this influences the camera's S/N performance.

Unregulated DC power supplies (usually in the form of plug-packs) are not very healthy for the CCD cameras. First, there is a high probability of blowing the camera's fuse when the power is switched on, owing to voltage spikes created when turning the load on (the camera in this instance). Second, there is an extra power dissipation that occurs in the camera when more than 12 V DC are applied.

Finally, if the camera does not have any further voltage regulations inside (DC/DC conversion), or if the regulations are of a bad quality, the unregulated voltage ripples may get into the readout pulses, thus affecting the video signal.

On the other hand, in most of the regulated power supplies there is a short-circuit protection. That means, even if the installer makes a mistake with the polarities or termination, the power supply will cut off the output, thus protecting the supply and the camera from further damage. Also, with regulated



AC and DC power supply voltage

power supplies, the voltage can be adjusted to compensate for voltage drops.

This is not the case with unregulated supplies.

Voltage drop has to be taken into account when powering distant cameras. This is especially critical with 12 V DC cameras since the voltage drop at lower DC voltages is more evident. This is a result of the $P = V \cdot I$ formula, where for a certain camera power consumption level, the lower the voltage is, the higher the current will be, indirectly increasing the voltage drop through a long run power cable.

Very similar logic applies when using numerous 24 V AC cameras powered from a single source (transformer). When calculating the total amount of current required for all the cameras, always leave at least 25% to 30% of spare capacity.

When AC cameras are used, attention should be paid first of all to the voltage rating (24 V is what the majority of AC-powered cameras require). Very often, power transformers can be purchased that have secondary voltage stated with the transformer fully loaded, as with halogen lamps. This might be misleading, since with big and constant loads, transformers may show lower voltage than they would have if only one camera was connected to it.

An AC camera's current consumption is very minimal (200 to 300 mA), so you should look for transformers with an open circuit of 24 V AC rating. Not by any means least important is the sine wave appearance, which can be especially critical when uninterruptible power supplies (UPS) are used. If a step-sine wave UPS is used, it may interfere with the camera electronics and phase adjustment. If a UPS is part of the CCTV system, a true sine wave is what we should always intend to use.

We will see in the following a very basic calculation for the voltage drop which occurs in the so-called ***figure-8*** cable that powers a single 12 V DC camera.

Copper wire size in AWG (cross section)	***#24 (0.22 mm²)***	***#22 (0.33 mm²)***	***#20 (0.52 mm²)***	***#18 (0.83 mm²)***
Resistance Ω/m	***0.078***	***0.050***	***0.030***	***0.018***
Resistance Ω/ft	***0.257***	***0.165***	***0.099***	***0.059***
Current rating (A)	***1.5***	***2.0***	***3.0***	***6.0***

The typical copper wire resistance, together with the cross section and the AWG (American Wire Gauge) is shown in the following table:

The popular figure-8 cable is, in most cases, a 14/0.20 type. The first number indicates the number of strands per conductor, and the second indicates the diameter of each strand in mm. The cross-sectional area of this cable is $14 \times (0.1)^2 \times 3.14 = 0.44\ \text{mm}^2$. The resistance for a copper figure-8 wire, per meter, is approximately 0.04 Ω. A typical manufacturer's specification for the 14/0.20 states approximately 8 Ω/100 m DC loop resistance (loop, meaning 2 × 100 m). Using these numbers we can calculate

Nearest AWG	Stranding (No./diam. in mm)	Copper area (mm^2)	Resistance (Ω/km)
10	65/0.30	4.59	4.0
12	41/0.30	2.90	6.0
14	26/0.30	1.84	9.4
14	50/0.25	2.45	7.0
16	7/0.50	1.37	13.0
16	16/0.30	1.13	15.3
16	30/0.25	1.47	12.0
17	32/0.20	1.00	20.0
18	16/0.25	0.78	23.5
18	24/0.20	0.75	26.0
19	1/0.90	0.65	27.0
20	1/0.80	0.50	35.0
20	7/0.30	0.49	35.0
20	9/0.30	0.64	28.0
20	10/0.25	0.49	35.0
20	16/0.20	0.50	39.0
21	1/0.70	0.40	46.0
21	14/0.20	0.44	44.0
22	1/0.64	0.32	54.8
22	7/0.25	0.34	54.5
24	1/0.50	0.20	89.2
24	7/0.20	0.22	84.3
26	1/0.40	0.13	136.0
26	7/0.16	0.14	139.4
28	7/0.127	0.08	221.5

the average voltage drop when powering a 12 V DC camera via a 300 m cable run, using the very simple Ohm's Law.

A realistic assumption would be that our 12 V CCD camera consumes 250 mA. This means that the camera is seen by the power supply as 12 V/0.25 A = 48 Ω resistor. For 300 m of 14/0.20 cable we will have a total loop resistance of 24 Ω. The supply voltage will now see a total resistance of 72 Ω. The 12 V will be divided between the R_c and R_{ccd} proportional to the resistance; that is, we will have a voltage divider. The calculation will show V_d to be 4 volts.

With a 4 V drop, the camera will most likely not work. Therefore, we have to increase the voltage (and a plug-pack cannot do this) to at least 16 V, according to this calculation.

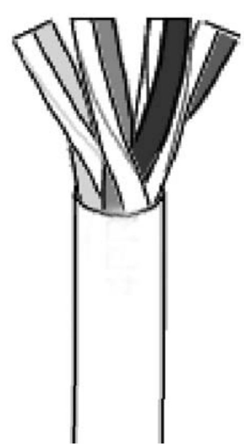
In practice, however, depending on the camera, we may only need as much as 13 V, for our camera under test may work properly with as low as 9 V (if we still assume around a 4 V drop). This would be the case if the camera's internal minimum requirement (due to further DC/DC regulations inside) were no higher than 9 V.

If we were to use a 24/0.20 cable instead, we would have a 15 Ω total loop resistance, and using the same calculations we would get only a 2.8 V voltage drop.

The conclusion is: **The thicker the cable we use, the smaller the loop resistance will be, thus a smaller voltage drop**. Increasing, or pumping-the-voltage-up, with a regulated power supply unit (PSU) may help, since the regulation range of such supplies is usually from 10 V to 16 V DC.

A similar principle applies to 24 V AC cameras, only then we are talking about RMS voltages (root mean square); therefore, it may look as though there is a smaller voltage drop.

Ohm's Law is valid for both AC and DC voltages, so if we try to calculate the voltage drops for when the camera is powered with, let us say 24 V AC, we have to consider two things: the current consumption is lower (since the voltage is higher), and the 24 V AC we refer to are really RMS, that is, 24 × 1.41 = 33.84 V_{zp} (volts zero-to-peak). So, by applying Ohm's Law, a mathematical calculation will obtain a lower voltage drop compared to the 12 V DC power, but this is only due to the different current and voltage numbers. In other words, a lower voltage drop with 24 V AC (and even lower with 110 or 240 V AC) is not because different laws apply to AC cameras, but simply because the voltage is higher. This is in fact the same reason power used in households is not distributed from power stations at the level it is used in the household, but it is raised to tens of thousands of volts. Thus, the current and voltage drop, due to the power cables' resistance with long distances, becomes acceptable.



For the purposes of easy calculation and further reference, located on the previous page is a table of the typical copper wires found on the market, showing the relation between the nearest AWG number, the most common stranding technique, the area in mm², and the resistance in ohms.

V-phase adjustment

AC-powered cameras are usually line-locked. This means that the vertical video frequency is synchronized with the mains frequency. If all cameras in a system are locked to the same power supply, that is, to the same phase (do not forget that we can have three different phases, each of them displaced at 120° relative to the other two), then we will (indirectly) have synchronized cameras.

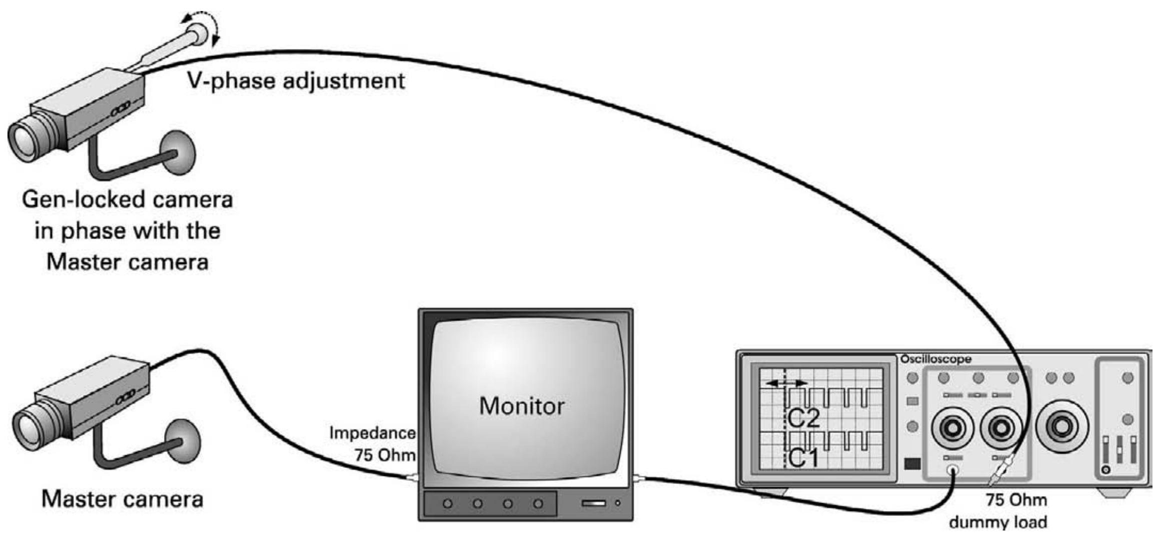
For the purpose of fine adjusting the vertical phase of each separate line-locked camera, a ***V-phase adjustment*** is available. V-phase adjustment can not only align the vertical sync of the cameras relative to their mains frequency zero crossing, but it can compensate even when different phase mains is used.

In order to do this, an oscilloscope with two channels is required. One camera is then taken as a reference, to which a monitor's vertical adjustment is set, so as to have no picture roll. The V-phase of the camera being adjusted is set so as to coincide with the V-phase of the referenced camera.

It should be noted that not all AC cameras are necessarily line-locked. That really depends on the camera design and provision in the electronics for such locking. If in doubt check with your supplier.



The majority of AC cameras have V-phase adjustment.



Line-locking cameras require two-channel oscilloscope and V-phase adjustment on the slave cameras, to follow the master one.

Camera checklist

In order to help people involved in installations, here is a list of things to be checked before the camera is installed in its position. Some may find this list very helpful, and others may even like to add a few more operations, specific to their particular system. Many integral cameras (fixed and PTZ) made in recent years do not require all of the steps listed below since many things are now factory preset. However, there are still many camera setups that may require your thorough checking.

So, it is advisable to check the following before a camera is installed:

* Auto iris plug. This usually comes with the camera, not with the lens. Unfortunately, there is no standard among manufacturers, although lately it seems that a majority of them are compatible, but still it is better to check. AI connectors of all shapes and sizes are available, although the square ones are most common. Keep the connector with the camera. It might be very hard to find a spare if you lose it. Also, keep the AI pin-wiring diagram that usually comes with the camera instructions.

* If a DC camera is used, be sure to work out which is the positive and which is the negative end of the power plug. Sometimes the tip is positive, and sometimes it is negative. For some DC cameras there is no need for polarity to be known, as they are auto-sensing.

* Do the back-focus in the workshop, especially if a zoom lens is used. Doing the back-focus on site will be at least 10 times harder. Follow the procedure described in the back-focus section, until you get more practice.

* Select a suitable lens for the angle of coverage required. For this purpose you can use focal-length viewfinders, hand calculators, tables, and so on. Take into account the CCD chip size, as well as whether you have a C-mount or CS-mount camera/lens combination. In the last couple of years vari-focal lenses have been used instead and adjusted on site. Sometimes they may not have a wide enough or narrow enough angle of view to suit the application, so a fixed focal lens may be the answer.

* Adjust the optimum picture for the estimated distance when the camera is installed. This is not so critical for a fixed lens, but installers tend to forget to adjust the camera focus on site, or unintentionally change the focus ring. If any out-of-focus problems appear, they will not be noticed during the daytime when the depth of field is big. They will become obvious and problematic at nighttime, when the depth of field is minimal.

* Make sure that the level setting of the auto iris is good for day and night situations. ALC adjustment is important only if a very high-contrast scene needs to be monitored. The level may need some adjusting depending on the picture contrast.

* Get the mounting screws for the camera (if installed in a housing) and the bracket. These are 1/4" imperial thread screws, usually 10 to 15 mm in length. Sometimes trivial things like this will slow your installation.

* Make sure the camera/lens combination fits in the housing. If a zoom lens is used, take into account the focusing objective protrusion when focused to the minimum object distance (MOD). This should not add more than 10 mm to the lens length.

* Set the ID of the camera if such a model is used.

* If a camera with a CCD iris is used, along with an auto iris, switch the CCD iris off. Alternatively, use a manual iris or remote-controlled iris lens. Auto iris and CCD-iris do not go together very well.

* Set a higher shutter speed if the application requires. This is usually the case when high-speed traffic is observed and the signal is recorded on a VCR or DVR. Have in mind, however, that with higher shutter speeds you will need more light on the object, and the CCD smear may become more apparent.

* Set the power supply voltage value to what is required, that is, take into account voltage drop. Also, consider the current required by all cameras connected to the supply.

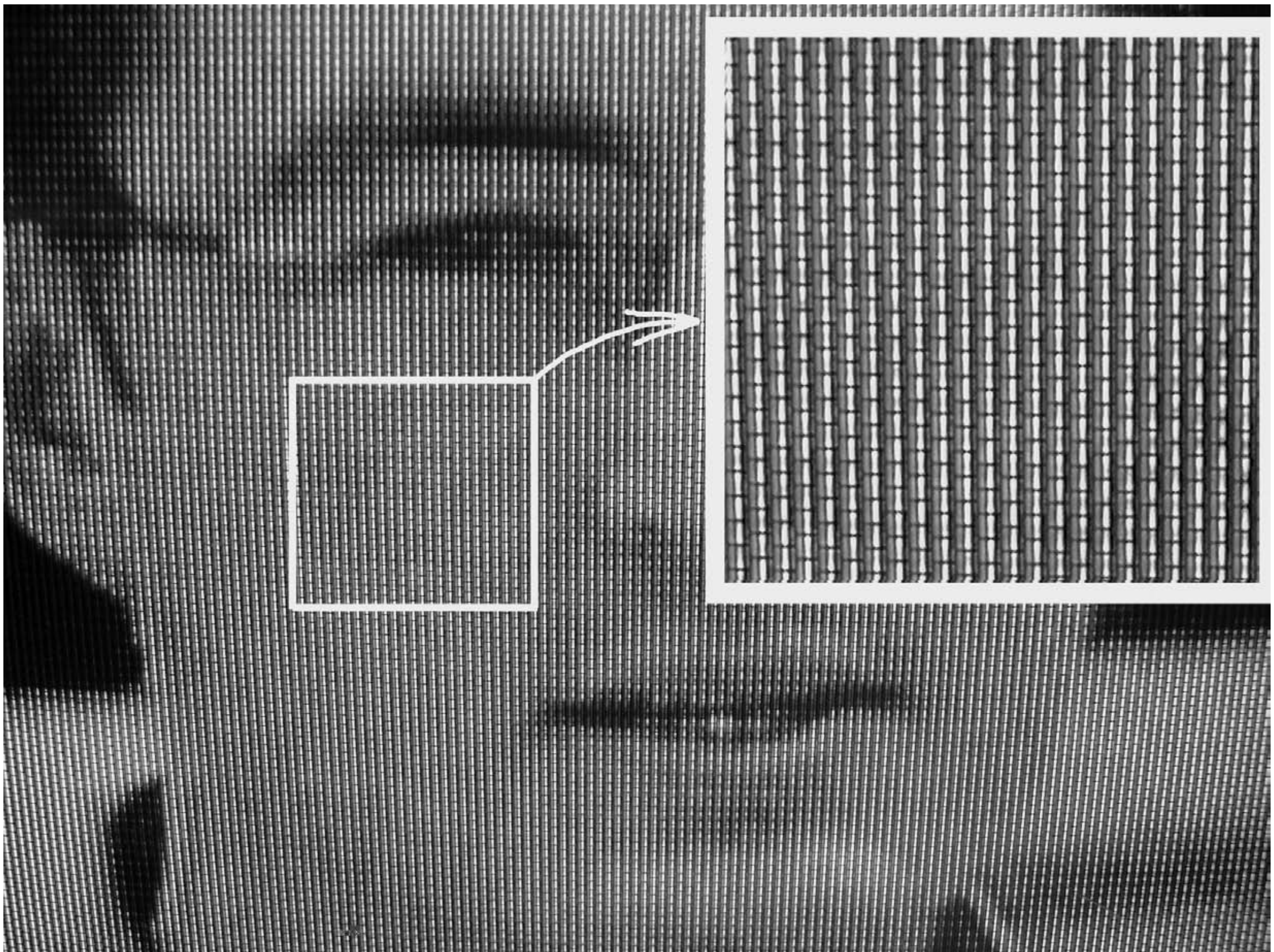
* If a 24 V AC camera is used and synchronization needs to be achieved, a V-phase adjustment may be necessary. You will need a two-channel oscilloscope and a reference camera for this purpose. Very often it is easier to make such adjustment in the workshop, and when such cameras are installed on site, just make sure they are powered from the same phase. Otherwise they will be displaced for 120º, as this is the phase difference in the mains three phase system.

* If a color camera is used, check the white balance setting. Some cameras have selectable indoor and outdoor white balance. Among the automatic white balance models you will find cameras with AWB (automatic white balance) and ATWB (automatic tracking white balance) selectable. In most situations ATW is the better choice.

* If a digital signal processing camera is used, set the parameters to suit the application.

* If a PTZ camera is used, set the camera ID, communication Baud rate data termination to the correct values.

* If a PTZ camera is used, do not forget the mounting brackets, either wall or ceiling mount, with the suitable cable connectors, conduits, and sealants (especially for outdoor installation).





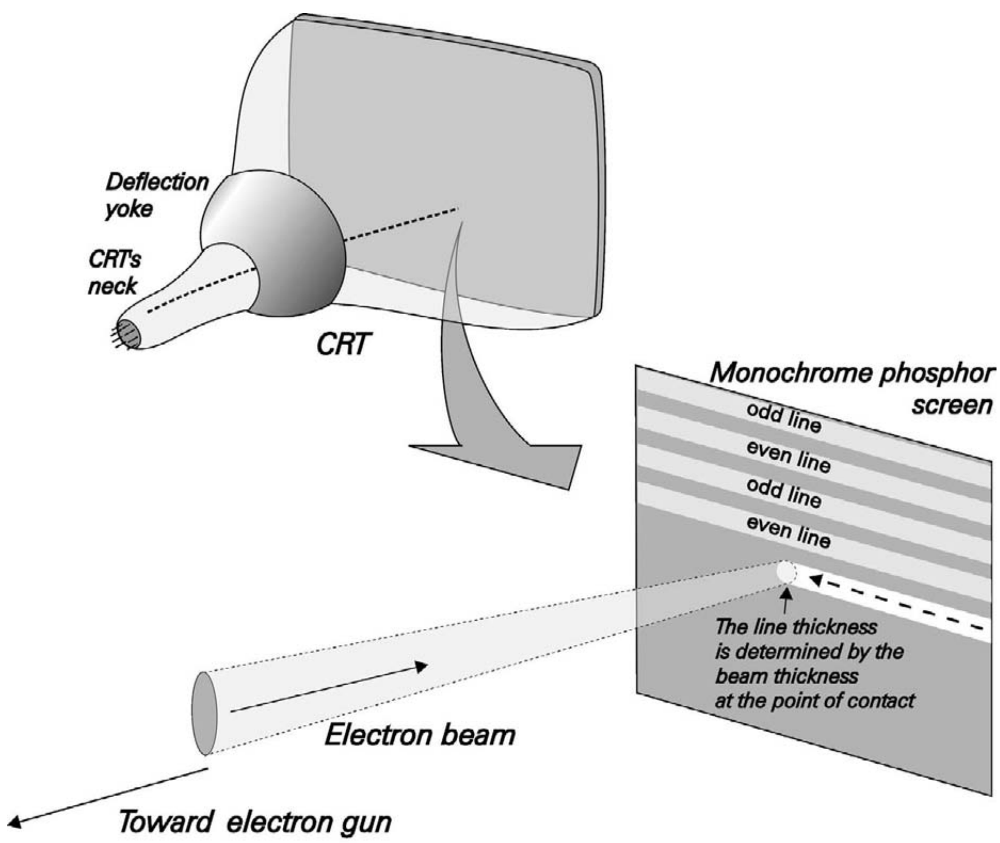
6. CCTV monitors

Monitors are often considered an unimportant investment in CCTV, compared to the other parts of a CCTV system. It is, however, very clear that if a monitor is not of equal or better quality than a camera, the overall system quality will be diminished. Simple but worthwhile advice is: pay as much attention to your monitor as you do to your camera selection.

General about monitors

Monitors display a video signal from a camera after it has gone through the transmission and switching media. The camera might be of excellent quality and resolution, but if the monitor does not reproduce equally or better than the camera, the whole system loses in quality.

In CCTV, as in broadcast TV, the majority of monitor display units are CRTs, which means they use cathode ray tube technology, designed to convert the electrical information contained in the video signal into visual information. Today, there are many alternatives to CRTs, such as liquid crystal display (LCD) monitors, plasma display, and rear projection monitors, but the most popular are still the CRT monitors.



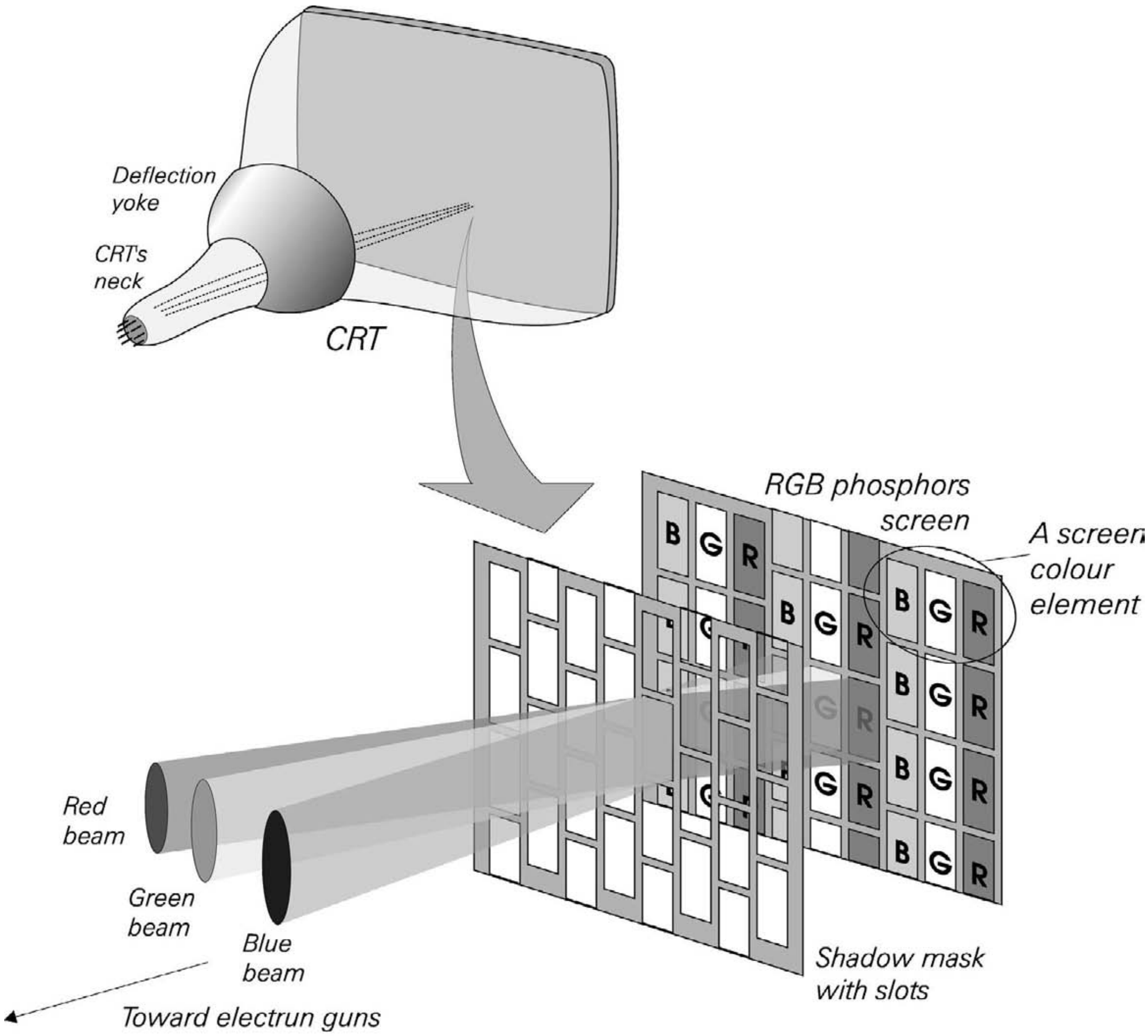
Monochrome monitor operation

The CRTs are coated on the inside with a phosphor layer that, when bombarded with electron beams, converts the kinetic energy of the electrons into light radiation. Different compositions of phosphor produce different colors. This is defined as the ***phosphor spectral characteristic***.

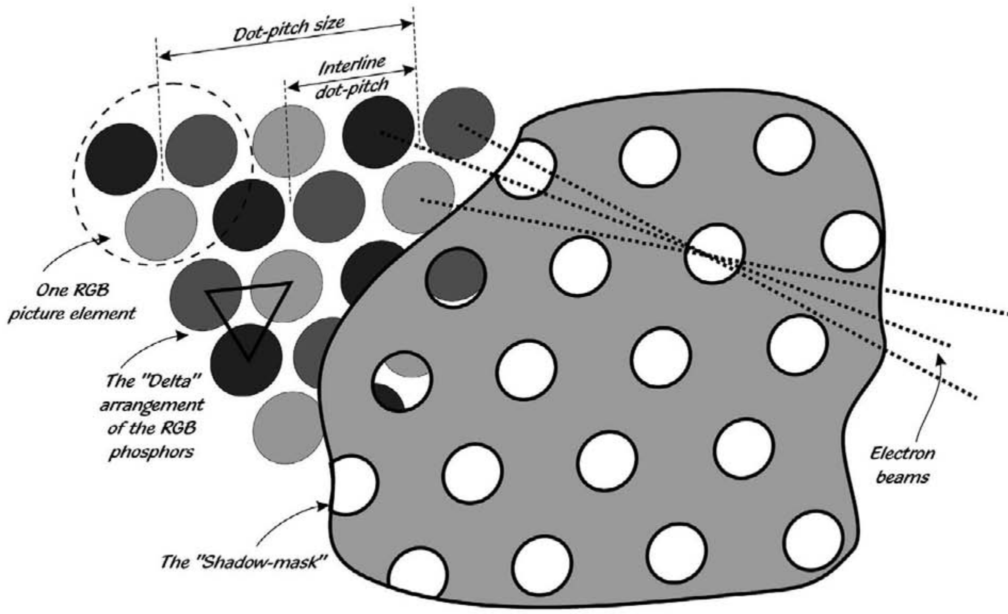
For a monochrome (or B/W) CCTV system, a phosphor layer that produces neutral color is used.

Color CRTs use a mosaic of three different phosphors that produce **red, green, and blue**, that are called ***primary colors***. These are little pixels (limited by the physical size of the mask) that, when viewed from a distance, mix into a secondary (resultant) color.

It has been proven that with the red, green, and blue primaries the majority of natural colors can be simulated. This kind of color mixing is called ***additive mixing*** because light is added by each of the primary components to produce the resultant color. This is contrary to the subtractive color mixing as in painting



The "In-line" type CRT has RGB pixel elements arranged in line, and every second displaced vertically by half in order to make the most of the interlaced scanning.

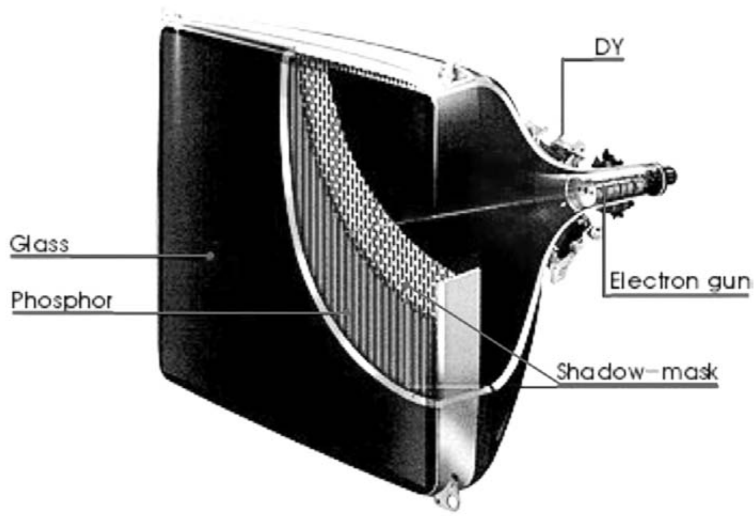


The "Delta" type CRT has RGB pixels arranged in a triangle.

and printing, where the term ***subtractive*** is used because these colors are produced by reflecting the light. In that case we have an absorption of certain colors (depending on the color pigmentation), thus a passive method of producing the resultant color.

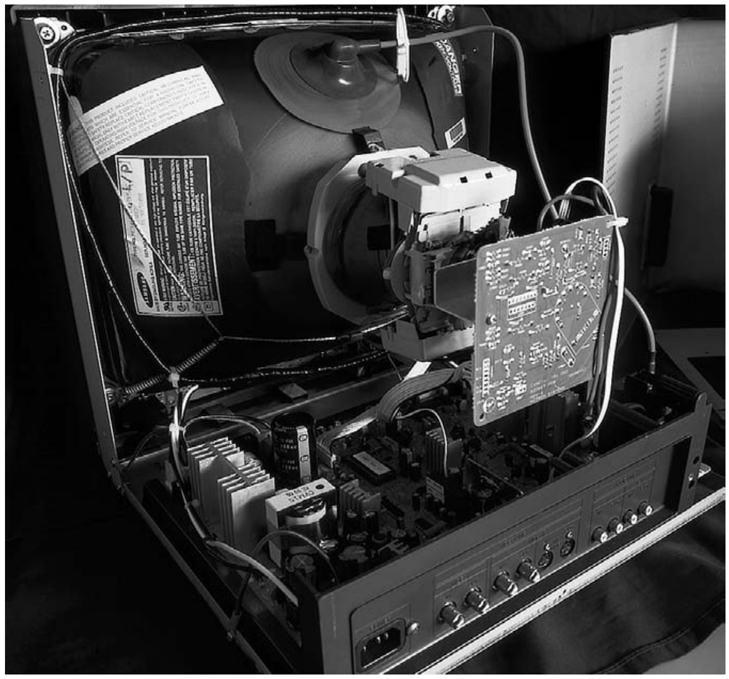
There are a few different technologies available for making color CRTs, based on how red, green, and blue phosphor elements are arranged. Some of these are patented technologies, such as the popular Sony's Trinitron. The other two common ones are the "***In-line***" as shown on the representation on the previous page and the "***Delta***" as shown above. These technologies are used in CCTV CRT monitors, but also in computers. The maximum resolution that can be reproduced is defined first by the smallest RGB elements, which make a ***color dot***, and their arrangement. This is usually specified in the CRT technical data as ***dot-pitch***. Current technology produces the smallest dot-pitch of around 0.21 mm. This then indirectly defines the smallest CRT screen size with a given resolution. This is one of the reasons small color monitors, for example, do not come in high resolution.

As in the human eye, an important property of the CRT phosphor is ***persistence***. The persistence of the phosphor layer is described as the duration of the luminance after the electron bombardment has stopped. Since the light produced does not disappear abruptly, but decreases slowly, persistence is measured until the time when the luminance produced decreases to 1% of its initial value. Phosphor persistence is a useful feature because it helps minimize the flicker, but it should not be longer than the TV frame duration (40 ms), as we want reproduction of dynamic images, whose movements would be blurred if the persistence were too long. The persistence of the majority of CRTs used these days is around 5 ms.



Cross section of a CRT

This is a bit more complicated with color monitors, since not all the phosphors have the same persistence (the blue phosphor has the shortest), but they are all around 5 ms.



A CRT monitor inside

Apart from the persistence, other important properties of the phosphor used in TV monitors are ***efficiency*** and ***spectral characteristics***.

Efficiency is defined by the ratio between the produced light flux and the electron beam power. The electron beam power depends on the acceleration produced by the CRT's high voltage and the electron beam itself. Different phosphors have different efficiencies; they can produce different luminance with the same amount of electrons and high voltage. In color TV, the phosphor that produces green color, for example, has the highest efficiency, and the red one has the lowest. Hence, the equation:

$$U_Y = 0.3\ U_R + 0.59\ U_G + 0.11\ U_B \qquad (46)$$

is applied to the electron beams of the R, G, and B colors in color television sets. This is all happening automatically inside a color monitor, and we do not have to worry about it, but it only indicates how delicate the color balance of the three primaries can be. Even a little stronger external magnetic field can affect the balance, which we sometimes see in the corners of monitors. To fix this, degaussing coils are used, which fire a very strong electromagnetic pulse when turning on a monitor. Magnetic color distortion occurs frequently when loudspeakers are near a monitor, or even if two monitors sit next to each other. Their own magnetic field affects the other's precision of reproducing red, green, or blue, and in order to minimize this, in CCTV we use metal-cased monitors. Reproducing colors correctly on a color monitor is a delicate process. Calibrating the camera with its white balance and color temperature is only the beginning. The same process is repeated in the CRT. White color balance in monitors is one of the most delicate adjustments in the manufacturing of monitors and TVs, since it is very difficult to be done by the human eye, which is easily adaptable. Special color probes are used for accurate tuning.

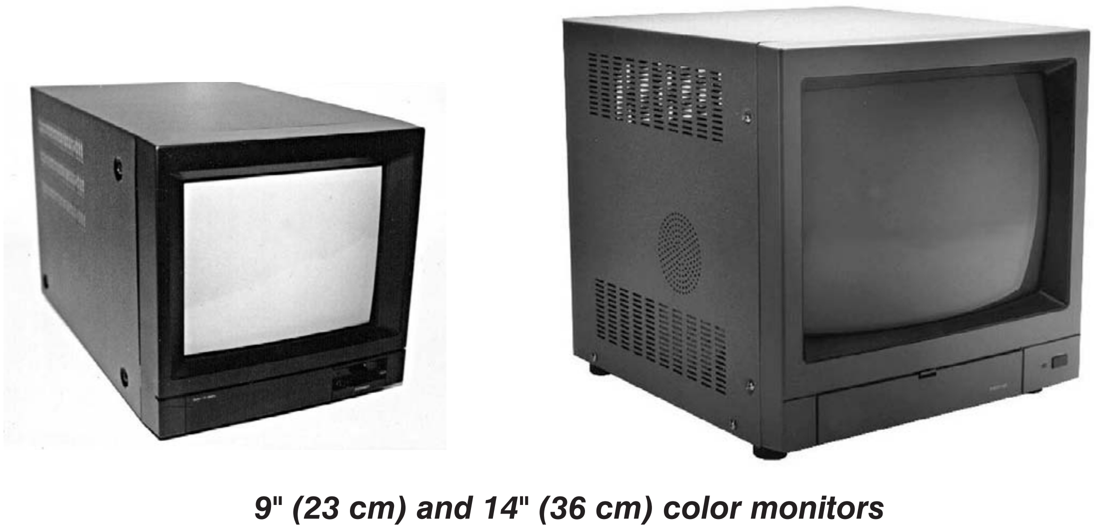
The basic division of monitors in CCTV is made into B/W and color, although lately, it is almost impossible to find a B/W monitor. Because of the TV standard's recommendations, there must be a compatibility between B/W and color. B/W video signal can be displayed on a color monitor, and a color signal can be displayed on a B/W monitor. B/W monitors have better resolution (since they have only one continuous phosphor coating) and are very useful in measuring resolution. The smallest dot element in B/W monitors is not defined by a dot-pitch (as there is none) but by the smallest electron beam cross section hitting the phosphor.

Monitor sizes

Monitors are referred to by their diagonal screen size, which is usually expressed in inches, but sometimes in centimeters. B/W monitors have a variety of sizes; most often used are 9" (23 cm) and 12" (31 cm). Smaller sizes, such as 5" (13 cm) and 7" (18 cm), are not very practical apart from, perhaps, vehicle rear vision systems, video intercoms and back-focus adjustments. Bigger ones are most often used where split-screen images are required, where sizes like 15" (38 cm), 17" (43 cm), and 19" (48 cm) are available.

The most popular color monitor size in CCTV is 14" (36 cm). This size is most suitable for the viewing distances typical in CCTV. There are 9" monitors (some manufacturers make 10" CRTs as well), which quite often are more expensive than the 14" ones. This is due to the massive production of 14" CRTs for the domestic market, which has brought the tube prices down. Larger color monitors, such as 17" or 20", are also available, but they are of a better quality and therefore more expensive.

A lot of installers prefer to use a 14" TV receiver instead of a proper monitor. This is usually due to the price advantage. TV receivers are produced by the hundreds of thousands and they have become very cheap. When such a display is used, you have to make sure the TV has audio/video inputs since, as we said earlier, in CCTV we use basic bandwidth video signals. In order to display the image on the screen the A/V channel has to be selected, that is, bypass the TV tuner. If the TV does not have an A/V input, this might be possible through the VCR A/V inputs, since VCR modulates the video signal at its output to the VHF or UHF band (usually channels 2, 3, 4, or 36). The picture quality of a TV receiver, when compared to a monitor's display, may or may not be of equal quality. This depends on the CRT, the receiver quality, and the input bandwidth, which are usually made to suit a 5 MHz broadcast signal. Another important factor to consider is that TV receivers are usually housed in a plastic shell and are not protected against electromagnetic radiation from another set next to it. As we know, in CCTV a few monitors may be positioned next to each other, and that is why CCTV monitors are usually housed in metal cabinets.



9" (23 cm) and 14" (36 cm) color monitors

Monitor adjustments

CCTV monitors usually have four adjustments at the front of the unit: **horizontal hold, vertical hold, contrast, and brightness.**

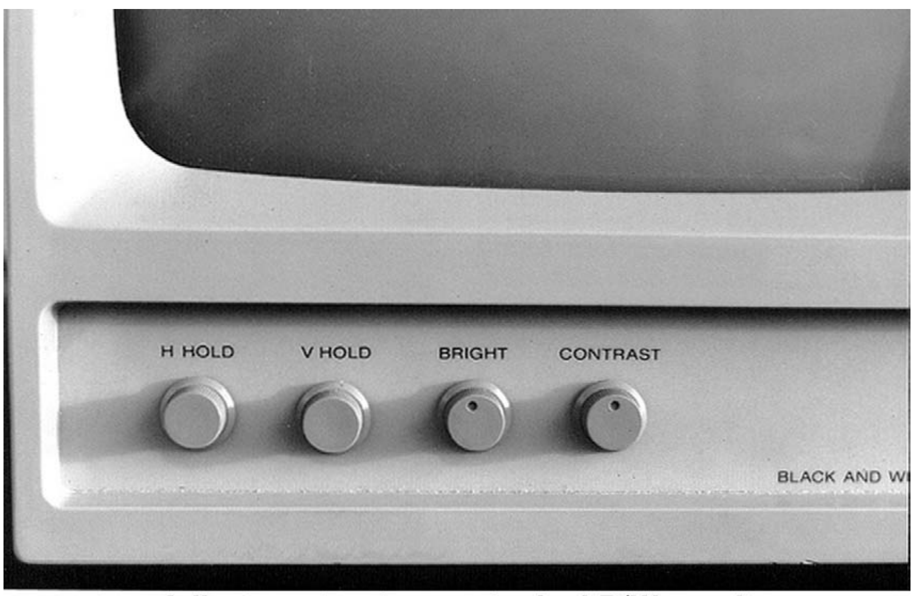
The ***horizontal hold*** circuit adjusts the phase of the horizontal sync of the monitor circuit relative to the camera signal. The effect of adjusting the horizontal hold is like shifting the picture left or right. When the horizontal phase goes too far to either end, the picture becomes unstable and horizontal scanning lines break. A similar effect may appear when the horizontal sync pulses are too low or deformed; this usually happens with long coaxial cable runs (voltage drop due to significant resistance and high-frequency losses due to significant capacitance). The last effect cannot be compensated for by the horizontal hold adjustments. By adjusting the horizontal hold, the picture can only be centered.

The ***vertical hold*** adjusts the vertical sync phase. This has an effect of compensating for various cameras' vertical syncs. Usually, a monitor is adjusted for only one video signal, and so the picture stays stable. However, when more nonsynchronized video signals are sequentially switched onto a monitor, an unwanted effect called *picture roll* occurs. This is perhaps the most unwanted effect in CCTV. It occurs owing to the monitor's inability to quickly lock to the various signals as they are switched through a sequential or a matrix switcher (this is also discussed in the switcher section). This also means that various monitor designs have various locking times. Better monitors lock to vertical syncs quicker.

In CCTV, switching numerous cameras onto one monitor is the most common system design. This is why we will devote some more space to explain the synchronization techniques used in CCTV. Very rarely, systems are designed where each camera goes onto its own monitor. Not only do the system costs become prohibitive, but the practicality of such systems is not sustained. First of all, physical space is required for more monitors, but more importantly no security operator can concentrate for long periods on so many different monitors.

Contrast adjusts the dynamic range of the electron beam, thus making the picture with higher or lower contrast (a difference from black to white). It is usually used when lighting conditions in the room (where the monitors are) change.

Brightness is different from the contrast adjustment because it raises or lowers the DC level of the electron beam, while preserving the same dynamic range. It is adjusted when the



Adjustment pots on a typical B/W monitor

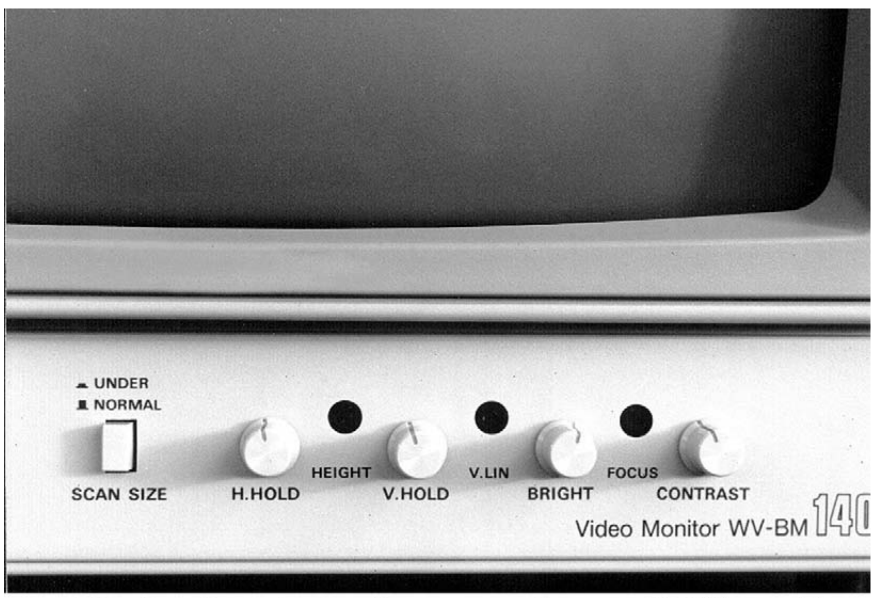
video signal tone reproduction is not natural.



The gray scale of a test signal is used to adjust brightness and contrast to optimum setting.

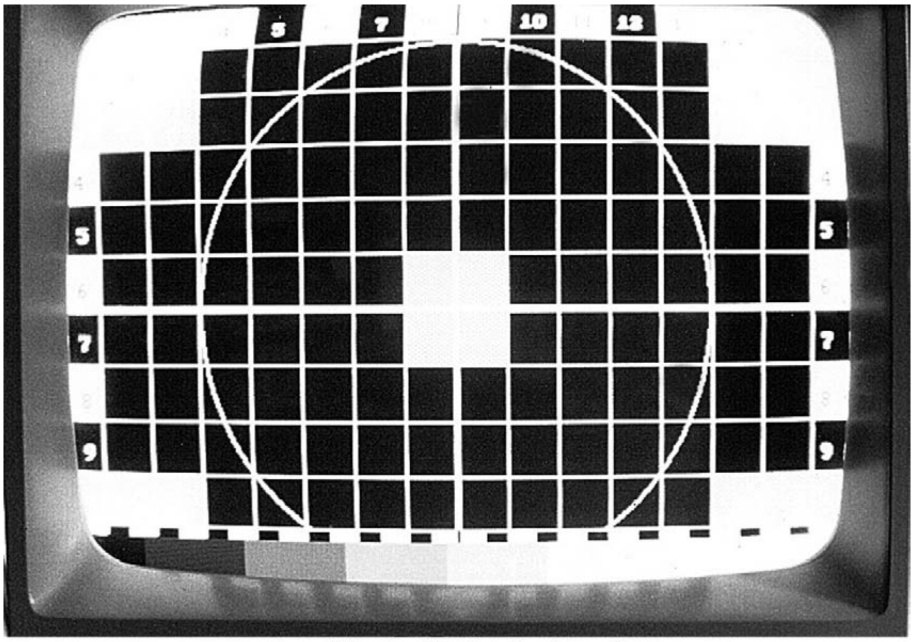
A simple rule of thumb is to have the brightness and contrast adjusted so that the viewer can see **as many picture details as possible**. The less light in the monitor room, the lower the contrast setting can be. By reducing the contrast, picture sharpness improves (smaller electron beam cross section), and the CRT lifetime is prolonged. Sometimes, brightness and contrast are hard to adjust properly, especially when switching different cameras with different video signals. In order to have an objective setting for the brightness and contrast, a test pattern generator that produces an electronic gray scale should be used (i.e., where the gray levels are equally spaced). Then, the contrast and brightness are adjusted so as to distinguish all of the steps equally well. After such an adjustment is made, the camera brightness and contrast can be judged more objectively. Consequently, we can decide whether a certain camera needs to have its iris level or ALC adjusted.

With time, the phosphor coating of a monitor's CRTs wears out. This is due to constant bombardment of the phosphor layer with electrons. The lifetime expectancy of a B/W CRT is around 20,000 to 30,000 hours. This means about a couple of years of constant operation. Worn-out CRT phosphor reproduces images with very poor contrast and sharpness. Color monitors should last a little longer because the smaller number of electrons (note that there are three separate beams for the three primary colors) are used to excite each of the three phosphors. In any case, after a few years of constant use, contrast and brightness adjustment can no longer compensate for the CRT's ageing, and that means the monitors need replacement.



The front controls of a more advanced B/W monitor

Sometimes, when a monitor is displaying one camera all the time, an imprinted image effect becomes noticeable (as was the case with tube cameras). If brightness and contrast adjustment are used carefully and in accordance with the ambient light, the monitor’s life can be prolonged. The same applies to the domestic TV receivers.

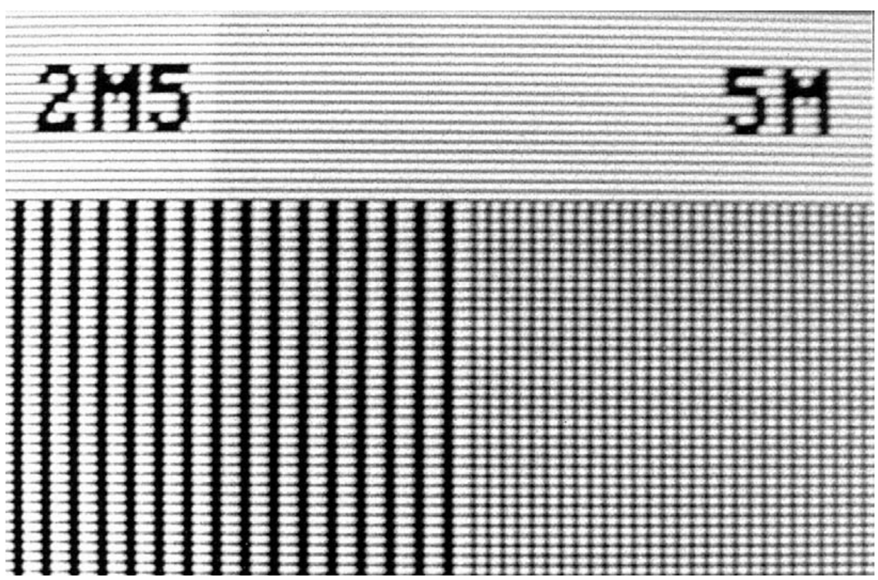


Linearity test signal

Linearity and ***picture height*** are two other adjustments, and are usually located at the back of the monitor.

Linearity adjusts the vertical scanning linearity, which is reflected in the picture’s vertical symmetry. If the linearity is not properly adjusted, circles appear egg-shaped. In order to adjust monitor linearity, a test pattern generator with a circular pattern is required. Sometimes a CCD camera can be used instead (CCDs do not have geometrical distortions) by positioning it to look perpendicularly at a perfectly circular object.

Picture height, as the name suggests, adjusts the height of the picture. With an improper picture height adjustment, the circles may appear elliptical. The scanning raster is also affected (increased or decreased), which indirectly changes the picture’s vertical resolution.

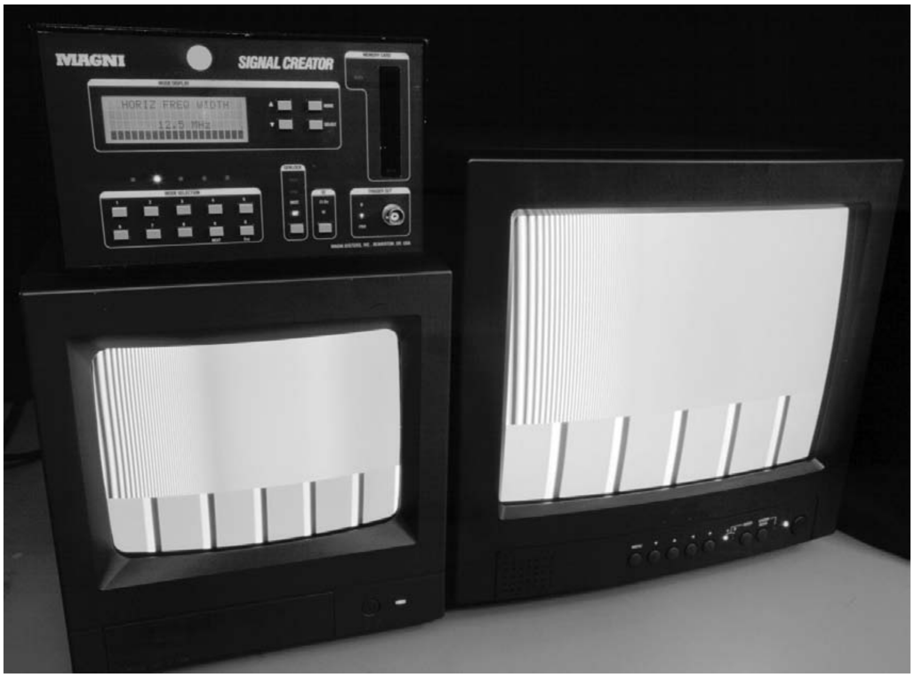


A close-up of a B/W monitor section showing 2.5 and 5 MHz test signal

Most of the monitors have ***electron beam*** **focus** adjustment, which is usually inside the monitor and close to the high-voltage unit. This adjustment controls the thickness of the electron beam when it hits the phosphor coating, indirectly affecting the sharpness of the picture. On some monitors, this adjustment may be located at the front of the monitor and could also be called *aperture*.

Color monitors have ***color***

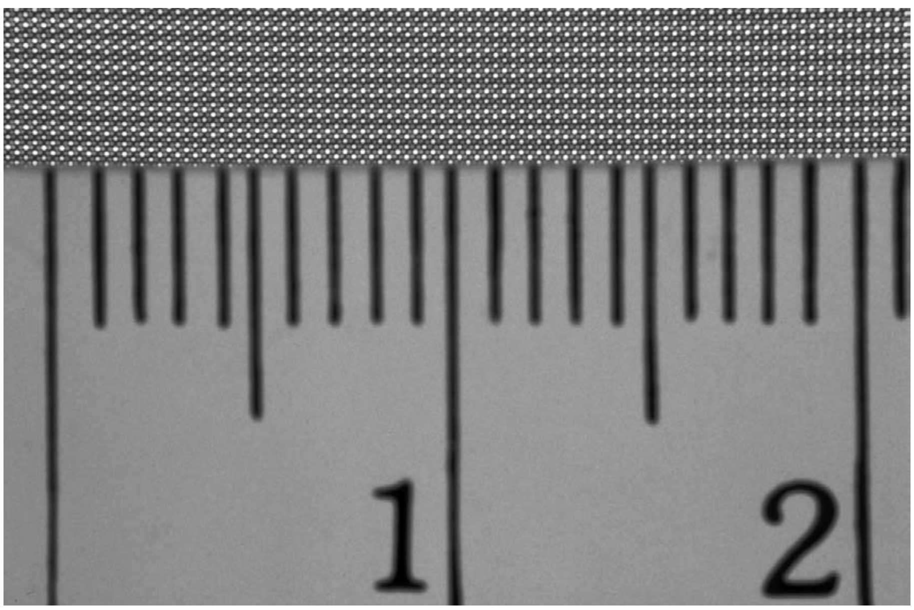
adjustment as well, which increases or decreases the amount of color in a color signal. This is different from brightness control. Color monitors are especially sensitive to static and other external magnetic fields because the color reproduction depends very much on the proper dynamic positioning of the three electron beams (red, green, and blue).



A special high-resolution sweep generator is used to check the bandwidth response of various monitors.

Even a slight presence of another magnetic field, such as a loudspeaker next to the CRT, may affect one of the beams more than the other two. This then results in unnatural colored spots in certain areas of the screen that are close to the magnetic field. In order to combat such effects, color TV monitors have an additional element in their design that is called a ***degaussing coil***. The degaussing coil is a conductor loop around the CRT, through which every time the monitor is turned on a strong current pulse is injected. This creates a short but strong electromagnetic pulse that clears any residual magnetic fields. If the external field is very strong and permanent, the degaussing coil might not be capable of clearing it.

Professional monitors (designed for the broadcast industry) are quite often used in bigger and better CCTV systems. They are equipped with sophisticated electronics and high-resolution CRTs whose horizontal resolution exceeds 600 TV lines. They quite often have some additional adjustments along with the ones mentioned above. These may include ***hue*** (which is actually the color itself: red, green, orange, etc.); ***saturation*** (representing the purity of

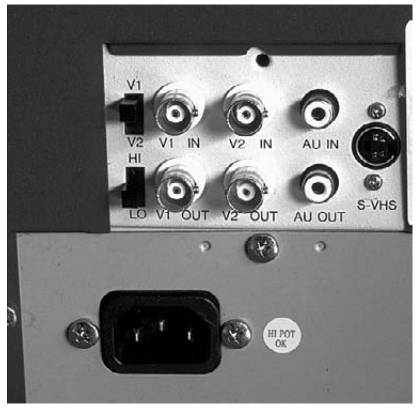


A close-up of the dot-pitch of a delta type color CRT, compared with the ruler below in millimeters.

the color, i.e., how much white is mixed into it, where 100% saturated color has no white additives); ***H-V delay*** (a very useful feature where horizontal and vertical syncs are delayed so that the CRT will show the signal broken up into four areas, similar to a quad, so that horizontal and vertical syncs can be visually checked); and ***underscan*** (where the monitor shows 100% of the video signal, which is especially important when testing camera resolution).

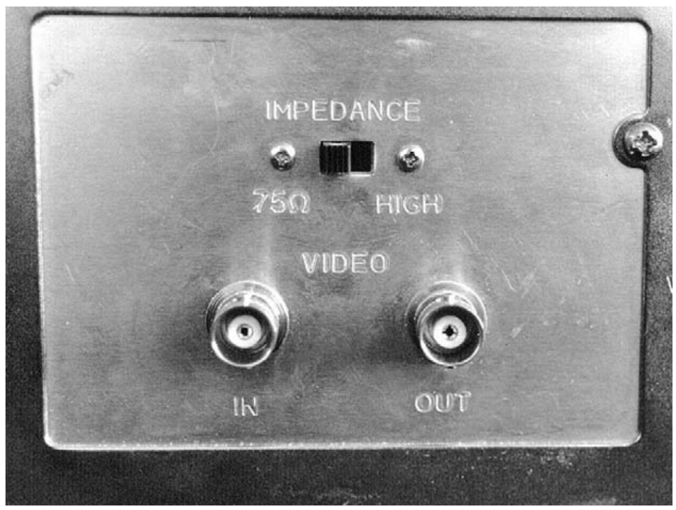
Impedance switch

At the back of most CCTV monitors is an ***impedance switch*** next to two BNC connectors. The purpose of the impedance switch is to allow for either terminating the video coaxial cable with 75 Ω (when the monitor is the last element) or leaving it to high position if the monitor is not the last component in the video signal path.



As we have already discussed, the video sources used in CCTV are all designed to have 75 Ω output impedance, which requires the same impedance from the signal receivers (monitors in this case).

Only then, we will have 100% energy transfer and perfect picture reproduction. If however, the monitor is not the last element in the signal path, but perhaps another monitor is using the same signal, we then have to set the impedance of the first monitor to high (looping monitor) and set 75 Ω on the last one (terminating monitor).



The manual impedance switch is usually at the back of monitors.

Most CCTV monitors have passive video inputs. There are monitors and other devices, such as VCRs, video printers, and video distribution amplifiers, where the video input is active. Active means the video signal is going through an amplifier stage and the signal is split into two or more components that are electronically matched with their impedances. In such cases, we do not have any switches to switch because there is no need for them. In other words, do not be confused if you cannot see an impedance switch on some professional monitors or VCRs. This will simply mean that the video input is automatically terminated with 75 Ω, and the output of it should be treated as a new signal coming out of a camera.



If a monitor does not have a manual switch, it means the electronics inside automatically terminate it.

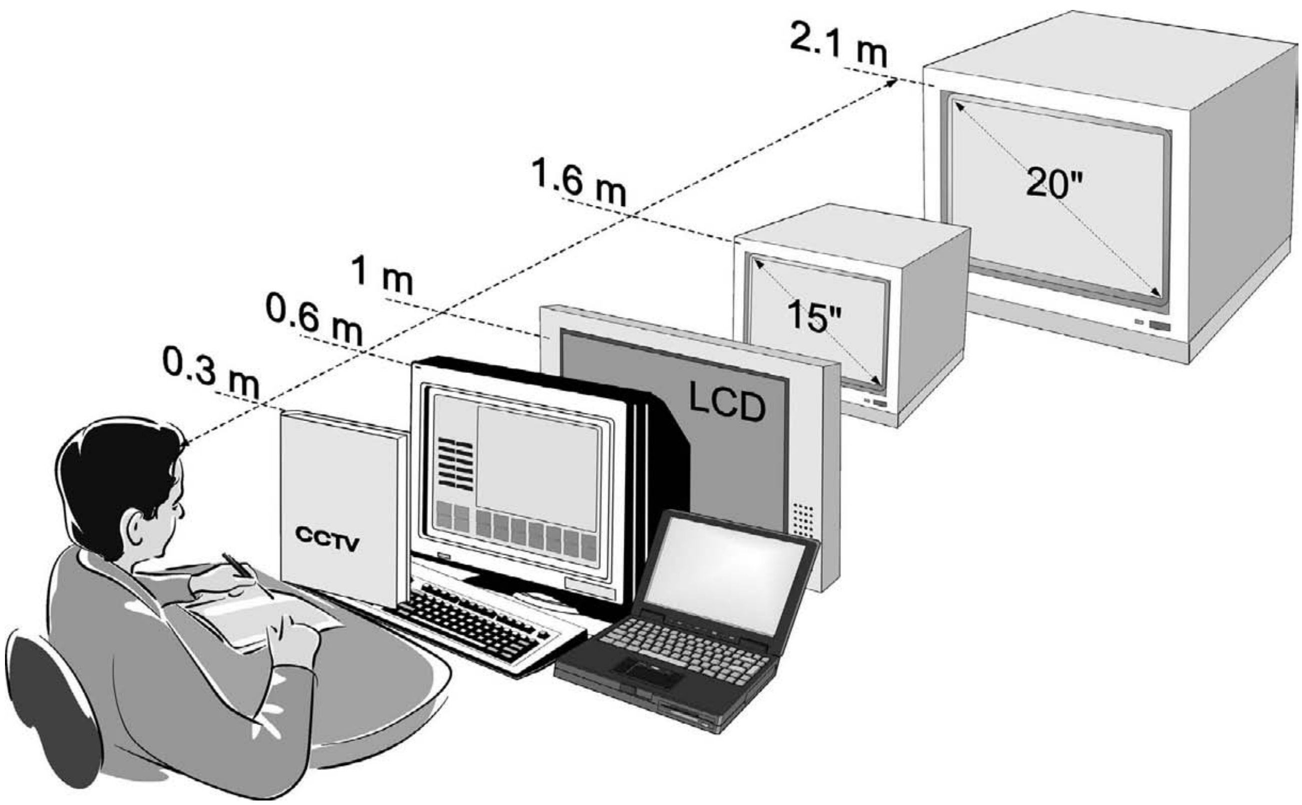
Viewing conditions

In a CCTV system the number of monitors can be quite large. It is very important to know how many monitors can be used in a place without going overboard, as well as how to position them and what will be the correct viewing distance for the users. Even with one monitor in the system, operators should be aware of certain facts and recommendations, especially when they are spending the majority of their time in front of the monitors.

The ***CCIR Recommendation 500*** (now called ITU) states that the preferred viewing conditions are affected by the field frequency of the TV system, the size of the screen and the distance, relative to the screen size.

Typically, for CCTV monitors, an **optimum distance is around seven times the screen height**. These recommendations are based on the practical resolution limits that the human eye has. In other words, these distances give the viewer the best detail for the given resolution (assuming of course 20/20 vision). This is explained in more detail in Chapter 9.

The table on the next page shows recommendations only, and one should be flexible when applying these recommendations in various circumstances, especially in considering the flicker effect in control rooms with a large number of CRT monitors. With big systems, where perhaps a dozen monitors need to be mounted in front of the operator(s), viewing distances may vary. It is also very important to plan and suggest the number of operators needed for a given number of monitors and control points.



Typical distances for optimum viewing of details

MONITOR SIZE	RECOMMENDED VIEWING DISTANCE
9″ (23 cm)	0.9 m
12″ (31 cm)	1.2 m
14″ (36 cm)	1.6 m
17″ (43 cm)	1.8 m
21″ (53 cm)	2.2 m

It is a known fact that the vertical flicker is noticeable with the peripheral vision of the eye. In other words, if you have many monitors to view, the vertical refresh rate of the surrounding monitors is affecting your vision even though you may be watching a monitor directly in front of you with easy comfort. For this reason, some manufacturers are now coming up with 100 Hz monitors for CCTV (this is more critical with PAL and SECAM because of their lower vertical frequency). The 100 Hz monitors simply double up the 50 fields refresh rate, and the display looks rock-steady. Sitting in front of such monitors for a longer period is a definite advantage, and I would suggest using such monitors where the display has to be of a bigger size. The bigger the monitor screen, the more noticeable the flicker.

Another important consideration is the electrostatic radiation of larger monitors. Although this radiation is negligible, when the walls of monitors are in one room they may have a significant influence on the environment, as can usually be confirmed by the amount of dust collected by such a large number of monitors. There is a low radiation standard accepted in the medical science called MPR II. This standard is also being accepted by some CCTV manufacturers and would clearly give an advantage to systems designed with such monitors.

With large systems, visual display management is of vital importance. For example, not all monitors need to display images all the time. It may be much more effective if the operator is concentrating on one or two active monitors (usually larger sized) and the rest of them are blank. In case of activity (i.e., an alarm activation, motion detection, or perhaps video fail detection), a blank monitor can be programmed to bring the image of a preprogrammed camera. In such a case, the operator's attention is immediately drawn to the new image and the system becomes more efficient. As an additional bonus, the monitor's lifetime will also be prolonged. Most of the video matrix switchers can be programmed to do such blanking and display alarmed cameras only when necessary.



A 100 Hz CCTV monitor with low MPRII radiation

Another subject relating to viewing conditions is the size of the monitor and its effect on the picture



Designing an efficient control room depends on the available space, the number of operators, and the size of the system (number of cameras to be viewed).

resolution. Clearly, whether a 9", 12", or 17" monitor is used, the resolution would still be more or less the same (assuming that the same quality of electronics is inside). The impression of picture sharpness however, may be different. So, a 9" monitor will be quite okay when a single operator views it at about 1 meter distance. But if a 17" monitor is viewed from the same distance (and this is usually for the reasons of viewing a quad picture, for example), when a full screen is displayed it will appear that the picture resolution is lower than with the 9" monitor. This is only an illusion attributed to the different viewing distance relative to the monitor's size.

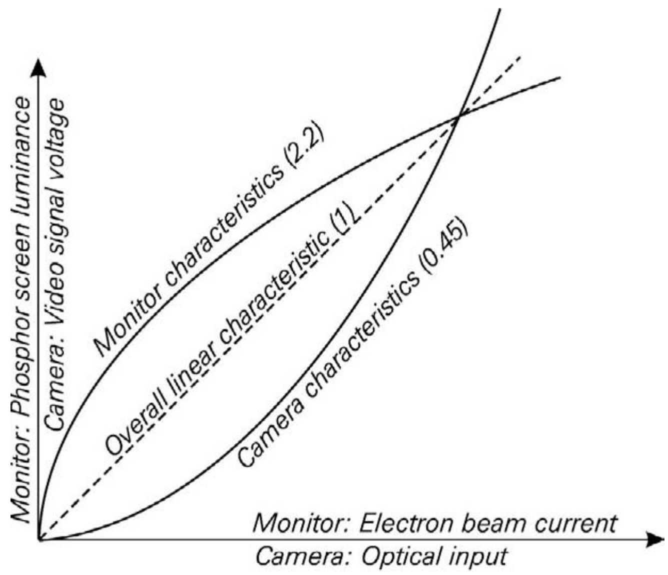


A central projector monitor is activated only when an alarm is triggered, attracting the operator's attention.

Other types of monitors that have to be considered in CCTV today are the rear-projection monitors, the screen projectors, the LCD, and the plasma monitors. Each of them has certain advantages, life expectancy, and specifics in regards to how they are installed.

Gamma

The CRT phosphor does not have a linear characteristic. This means that if a linear signal is displayed (continuous rising ramp from black (0 V) to white (0.7 V)), it will not have the same rate of luminance rise. The monochrome monitor's characteristic of the electron beam current versus luminance produced by the beam is a parabolic function with a power exponent of 2.2.



Gamma explained

Ideally, we would like to have a linear CCTV system. This would mean linear reproduction of the gray levels and colors. But since the CRT phosphor coating is, naturally, without a linear characteristic, we have to somehow compensate for it. This compensation is easiest done at the camera end. If the CCD camera's characteristic luminance-versus-voltage (usually linear) is electronically modified to have an inverse characteristic of the CRT (1/2.2 = 0.45), we will get a linear camera-monitor system.

When these two curves (of the monitor and camera) are put together on a single diagram, they are symmetrical around a straight line of 45°. This resembles the mathematical symbol γ (***gamma***), hence the name.

In practice, if you have a camera with a gamma setting that is not complementary to the monitor's characteristic, the picture quality will not be as good. This is reflected in the unnatural reproduction of gray levels where the picture has high contrast, lacking details in the middle gray range.

Most B/W monitors have a 2.2 gamma value; therefore, 0.45 should be the common default setting for a B/W camera. Naturally, CCD cameras have a linear gamma value (1).

Color monitors are especially sensitive to the gamma effect, and as mentioned earlier in Chapter 4, the NTSC and PAL systems are designed with two different assumptions for the color phosphors gamma values. Theoretically, as assumed in NTSC, gamma should be 2.2, but in practice most of the phosphor coatings are close to 2.8, as proposed by PAL. Higher values of gamma have the appearance of higher contrast images. Clearly, this depends not only on the standard (NTSC or PAL) but also on the type of phosphor coating inside the monitor's CRT.

Today, gamma is an even more sensitive issue, especially when using just standard computer monitors for displaying digital video recording material. It should be known that various operating systems, video drivers, and programs control gamma differently.

LCD monitors

LCD stands for ***liquid crystal display***, which refers to organic substances that reflect light when voltage is applied. LCD technology was introduced back in 1970, but it was long inferior in its image quality. The liquid crystal display consists of a liquid suspension between two glass or plastic panels. Crystals in this suspension are naturally aligned parallel with one another, allowing light to pass through the panel. When **electric current is applied, the crystals change orientation and block light instead of allowing it to pass through**, turning the crystal region dark.



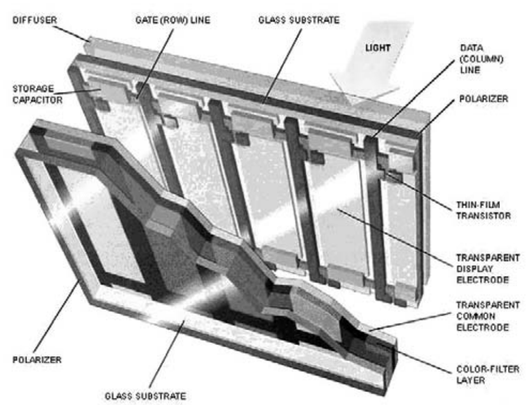
LCD monitors are small and elegant.

The concept of LCD operation is quite different to the CRT principles. Perhaps, the best description, or analogy, would be that LCD monitors compared to CRT monitors are what CCDs are to tube cameras. The image is not formed by electron beam scanning, but by addressing liquid crystal cells, which are polarized in different directions when voltage is applied to their electrodes. The amount of voltage determines the angle of polarization, which as a result determines the transparency of each pixel, thus forming an element of the video picture. The early version of liquid crystals was unstable and unsuitable for mass production. Today, things have changed. LCD monitors are also known as flat-panel, dual-scan, active matrix, and thin film transistor (TFT).

The advantages of the LCD includes the following: no need for high-voltage elements; no phosphor layer wear (i.e., unlimited lifetime of the screen); a flat and miniature appearance; no geometrical distortions; low power consumption; and no effect from electromagnetic fields as is the case with CRTs. In addition, LCD prices are going down, while providing better brightness and sharpness. This is the main reason consumers and end-users are switching from the conventional CRT to LCD. Previous LCD technologies were slower and less efficient, and provided lower contrast.

Although there are basically two kinds of LCD – DSTN (***dual-scan twisted nematic***, also known as ***passive***) and TFT (***thin film transistor***, also known as ***active matrix***) – today we almost exclusively use TFT-based panels.

LCD consists of several layers that are arranged in the following order: polarizing filter, glass, electrode, alignment layer, liquid crystals, alignment layer, electrode, glass, and polarizing filter. The cross section of the TFT LCD panel looks like a multilayer sandwich. At the outermost layer on either side are clear glass substrates. Between the substrates are the thin film transistor, color filter panel that provides the necessary red, blue, and green primary colors, and the liquid crystal layer. At the back of the LCD is a fluorescent backlight that illuminates the screen from behind. Under normal conditions when there is



Courtesy of hwextreme.com

The LCD concept

no electrical charge, the liquid crystals are in an amorphous state, in which, the liquid crystal passes through. By subjecting the liquid crystal layer to varying amounts of electrical charges, the liquid crystal layer will allow different amounts of light to pass through, as they orientate themselves according to the control center for the liquid crystals.

Just as in an ordinary CRT, the red, green, and blue liquid crystal “chambers” make up one pixel (picture element). By subjecting the red, green, and blue chambers to varying degrees of electrical charges, different colors can be achieved. As in the CRTs, we have a certain size of the LCD pixels which defines how many lines can be seen on screen. The typical LCD pixel size is around 0.28 mm, which is sufficient to produce a 1024 x 768 resolution screen on a 14" notebook computer screen.

One other important parameters of the LCD screen is the ***pixel response time***. The shorter the better, but it is known that pixel response time is not as quick as electron CRTs, which is one of the reasons LCD monitors require lower video frequency to produce a stable image.

Also, the ***viewing angle*** is an important parameter of an LCD screen. These days it is not uncommon to have one greater than 120º.

And finally, one of the weakest parameters in LCDs (compared to CRTs) is the ***contrast ratio***. In CRTs it is easier to produce higher contrast, even though the total brightness of a CRT may be lower than in LCD screens, simply because the electron gun can be completely shut down if the image needs to display black. In LCD monitors, the backlight is always on, and no matter how good the LCD pixels are in blocking light, when black needs to represented, there is a certain amount that still comes through. For a good LCD display, a typical contrast ratio should be at least 400 to 1.



The largest of them all: Apple’s 30" screen with astounding 2560 x 1600 pixels

On the positive side, LCDs do not have the CRT’s geometric, convergence, or focus problems, and their clarity makes it easier to view higher resolutions at smaller screen sizes. Also, the latest LCD monitors are all digital, unlike CRTs. This means that graphics cards with digital outputs do not have to convert the graphics information into analog form as they would with a typical monitor. Theoretically, this makes for more accurate color information and pixel placement. In contrast, LCDs that plug into standard analog VGA ports actually have to perform a second conversion back to digital (because LCD panels are digital devices), which can result in distracting artifacts.

Because of the precise and discrete nature of each pixel element in LCD screens, the sharpest and best image appearance is achieved when the video card resolution is made to match the native resolution of the LCD screen. In other words, if the LCD screen is 1280 × 1024 pixels, the video card setting on the computer should be set to this mode, not lower or higher. Some LCD monitors have composite video input, Y/C, and high-resolution RGB (computer) inputs. When such a monitor is used as a composite, the LCD monitor electronics does oversampling in order to fit the composite video into an XGA resolution, for example.

The following are widely accepted computer screen standards in pixels, which we may come across in CCTV:

VGA: 640 × 480

SVGA: 800 × 600

XGA: 1024 × 768

SXGA: 1400 × 1050

UXGA: 1600 × 1200

WSGA: 1640 × 1024

WUXGA: 1920 × 1280

Apple 30": 2560 × 1600

Projectors and projection monitors

Although CRT monitors are the most widely used, they can only be so big, for their physical size is limited primarily by the high voltage required to accelerate electrons over their size. The largest CRTs used in CCTV are hardly bigger than 68 cm (27"). But there are other ways of producing a larger picture, and this is usually by projection methods. Some years ago, projection monitors were extremely big, expensive, and complicated for use and setup. They would usually consist of three separate optical systems, each projecting its own primary color. Today, video projectors are much smaller, cheaper, brighter, and easier to use and set up. In most cases, they would accept a range of video inputs such as composite video, RGB (or component) video, Y/C, computer video S-VGA, and the like. Most of the projectors are single-lens color projectors that filter the light through an LCD film.



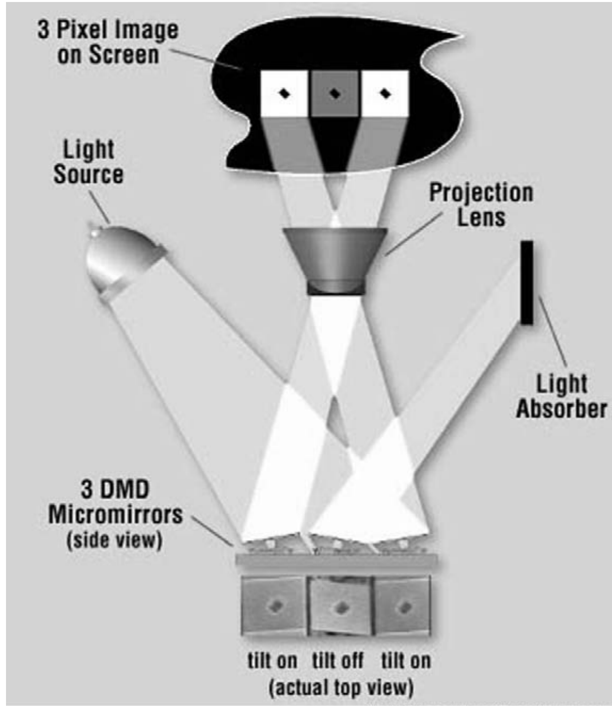
An LCD projector

One of the biggest advantages of projectors is their ability to produce almost any size image required, depending upon the wall or screen size. They may not have the same brightness as CRT, but technology advances very rapidly, and brighter and brighter projectors are on the market.

The brightness is usually expressed in lumens, and a typical LCD projector would have over 1500 lumens, which is sufficient for even brighter rooms. Their resolution is increased, and with the advances of the LCD technology we can get projectors with resolution well over XGA and up to SXGA mode, more than sufficient for high-quality computer presentations, broadcast video, and certainly CCTV.

There are two main technologies here, both of which use a strong source of light, the LCD and DLP (digital light processing) projectors. The DLP technology offers brighter and sharper images, but

certainly LCD technology gets better too.



The light reflection process in a DMD

The DLP idea was developed by Texas Instruments™ and is based on the ***micro-mirror device technology***. This is basically a memory chip with a matrix of millions of microminiature mirrors (similar size and appearance as CCD chips). A light source projects an image to the DLP chip so as to have the mirrors reflect the image onto virtually any size screen. The size of each mirror is 26 millionths of a millimeter. The mirrors are so small that a grain of salt could obscure hundreds of them. Each mirror represents a screen pixel. All are controlled and switched on and off by the on-chip circuitry, and every one of the hundreds of switches per second is performed with great precision and accuracy. The mirrors are programmed to remain at designated reflective angles for various time periods within a single frame of motion. This permits gray-scale projection or correct color presentation. For color projection the light is beamed through a condenser lens and then through a red, green, and blue color sequential filter. The filter switching is synchronized to the video information fed to the DLP chip at a rate three times that of the video (which results in 150 Hz switching for PAL and 180 Hz for NTSC signals).

Filtered light is then projected onto the DLP integrated circuit, whose mirrors are switched on or off according to the digital video information written into the chip's memory circuits. Light shined on these mirrors is then reflected into a lens to project images from the DLP surface. The full color digitized video image created on the DLP displays onto either a front or rear projection screen. Depending on whether one or three DLPs are used, high brightness projection screen size can range anywhere from 1.5 m to 5 m (diagonally). By applying a zoom lens projection, the image size can be increased or decreased to virtually any screen size. But the most important benefits (apart from the miniature physical size itself) include equal high resolution, brightness, and color fidelity, regardless of the screen size.



The heart of the DLP projectors, Texas Instruments' patented digital light processing chip

Because of the individual digital processing of each DLP pixel, this technology and these types of projectors are also known as ***digital light processing*** (DLP) projectors.

Plasma display monitors

Some scientists refer to ***plasma*** as the fourth state of matter (the first three being solid, gas, and liquid). Often plasma is defined as an ionized gas. The theory of plasma is beyond the scope of this book, but we would like to mention the usage of plasma in display monitors.

These monitors are made of an array of pixels, each composed of three phosphor subpixels – red, green and blue. As opposed to CRTs where light radiation was caused by electron bombardment, in the plasma displays, gas in plasma state is used to react with phosphors in each subpixel. In plasma displays each subpixel is individually controlled in order to get 16.7 million colors.

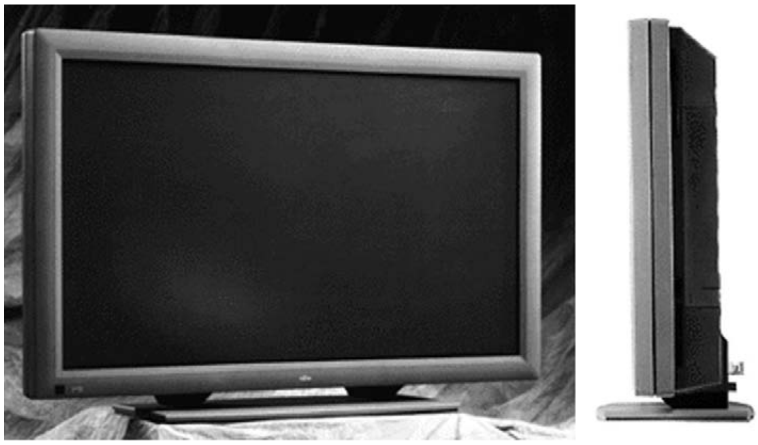
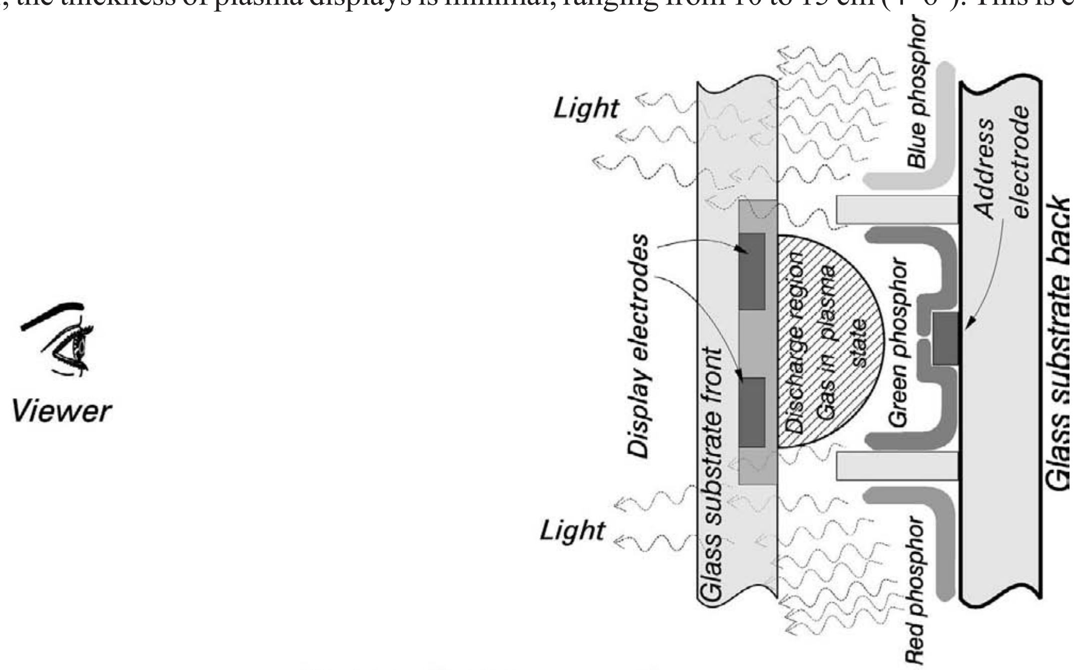


Photo courtesy of Fujitsu

Plasma display

Because of the fact that each pixel is excited with the plasma process individually there is no geometrical distortion as is the case in CRTs, and the picture sharpness and color richness are brought up to new heights. The picture contrast is also high, typically over 400:1, making the plasma displays suitable for bright areas.

Since the plasma display does not require high voltage as is the case with CRT, larger displays are possible. Typical plasma display sizes are from 105 cm (42") up to 125 cm (50"). More importantly, however, the thickness of plasma displays is minimal, ranging from 10 to 15 cm (4–6"). This is especially



Plasma display concept

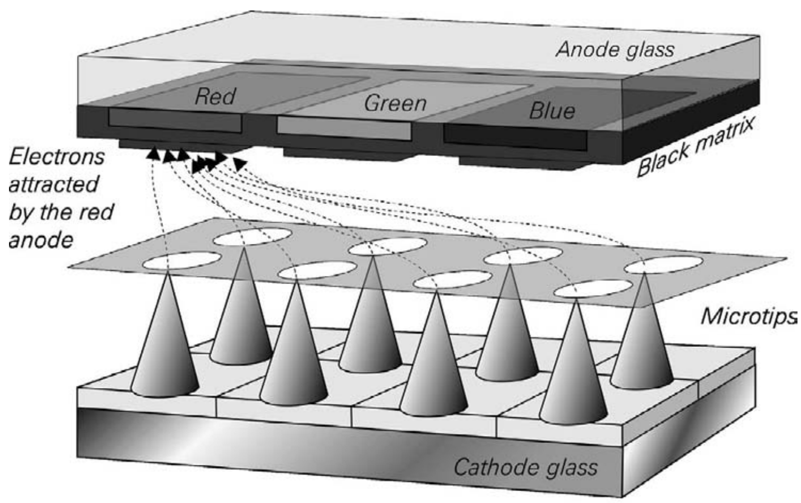
attractive for aesthetic reasons, but also for rooms with limited space.

Since plasma displays are based on phosphor coating, they also fade with time. Manufacturers usually claim 30,000 hours for the brightness to get reduced to 50% of its original quantity. This is equivalent to about three years of constant operation, which is more or less the same as what the CRT monitors are quoted as.

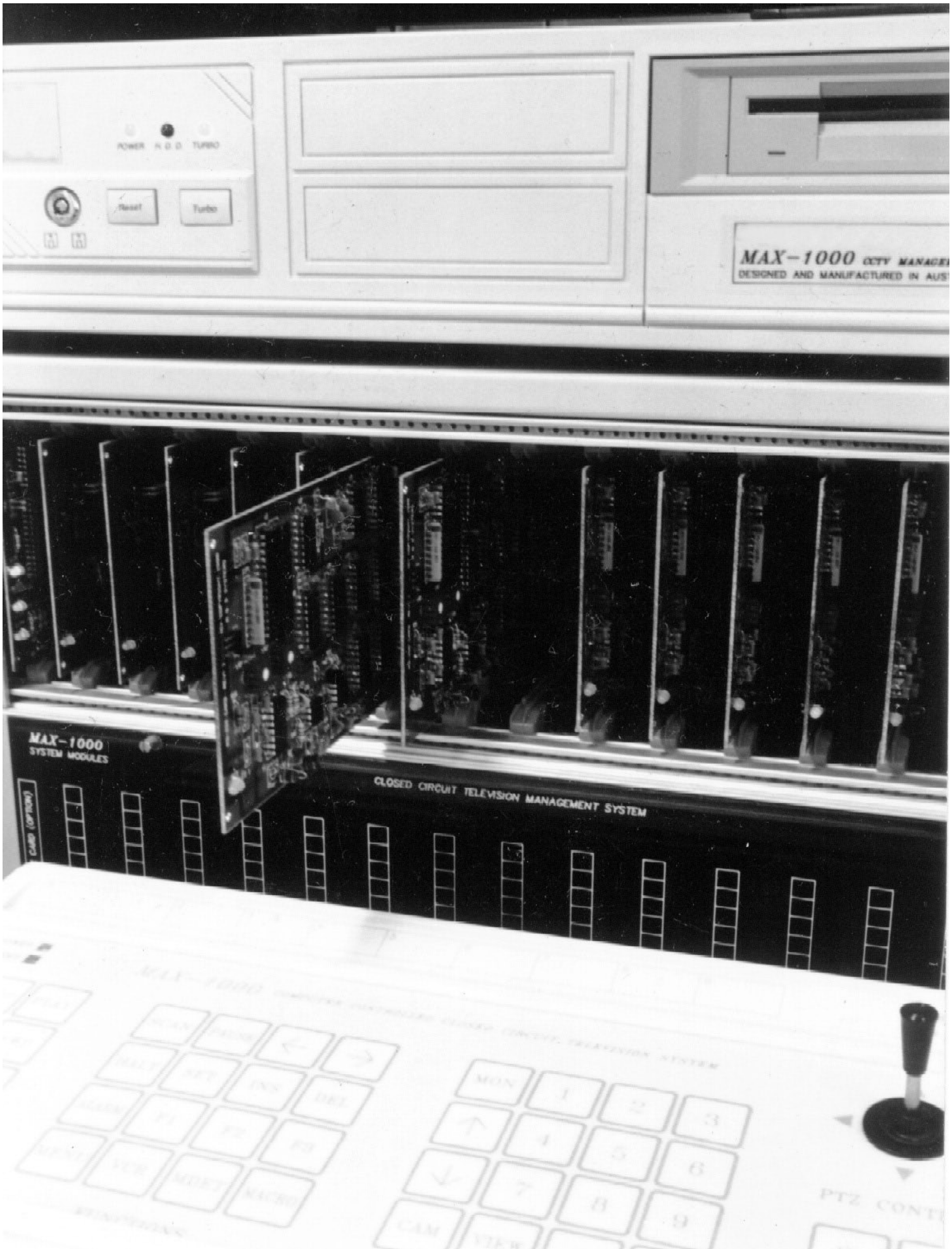
Field emission technology displays

Another alternative for better image displays, but on a standard screen size and not a projection screen, was presented by Motorola™ about five years ago. The concept is a flat display with active light emission called ***field emission device*** (FED) technology. Instead of a single cathode ray source, as is the case with a standard CRT display, the FEDs rely on hundreds of little cathode ray sources for each pixel. FEDs are composed of two sheets of glass separated by a vacuum. The back glass, or cathode, is made up of millions of tiny tips that form the source of electrons that accelerate across the vacuum. The front glass, or anode, has layers of standard CRT phosphors.

The FED display, it is claimed, offers many of the anode glass benefits of a CRT display, but it is thinner, lighter, uses less power, and has no geometrical distortions. The addressable x-y emitter layout eliminates the nonlinearity and pincushion effects associated with standard CRT images. The companies developing the FED are claiming that these types of display devices will be cheaper and easier to manufacture than LCDs, and considering there is no need for a single RGB gun that dictates the equivalent CRT size and appearance, the FED display will be larger, yet thinner and lighter.



The field emission display concept



POWER
H.D.D.
TURBO
Reset
Turbo
MAX-1000
DESIGNED AND MANUFACTURED IN
MAX-1000
SYSTEM MODULES
CLOSED CIRCUIT TELEVISION MANAGEMENT SYSTEM

7. Video processing equipment

Only very small CCTV systems use the simple camera-monitor concept. Most of the bigger ones, in one way or another, use video switching or processing equipment before the signal is displayed on a monitor. With the introduction of digital video recorders, these functions are slowly starting to be done digitally, but in this chapter we are going to cover the good old analog switching equipment.

The term ***video processing equipment***, as used here, refers to any electronic device that processes the video signal in one way or another, such as switching between multiple video inputs, compression into one quadrant of the screen, and boosting of the higher frequencies.

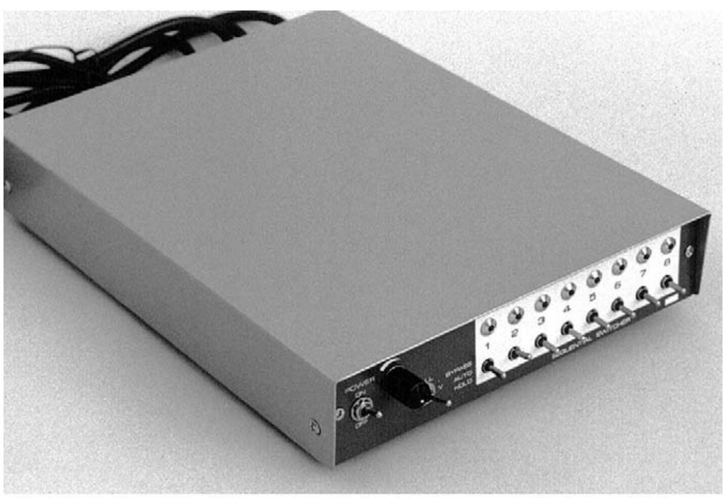
Analog switching equipment

The simplest and most common device found in small to medium-sized CCTV systems is the video sequential switcher. As the name suggests, they switch multiple video signals onto one or two video outputs sequentially, one after another.

Video sequential switchers

Since in the majority of CCTV systems we have more cameras than monitors on which to view them, there is a need for a device that will sequentially switch from one camera signal to another. This device is called a ***video sequential switcher***.

Sequential switchers come in all flavors. The simplest one is the 4-way switcher; then we have 6-way, 8-way, 12-way, 16-way, and sometimes 20-way switchers. Other numbers of inputs are not excluded, although they are rare.

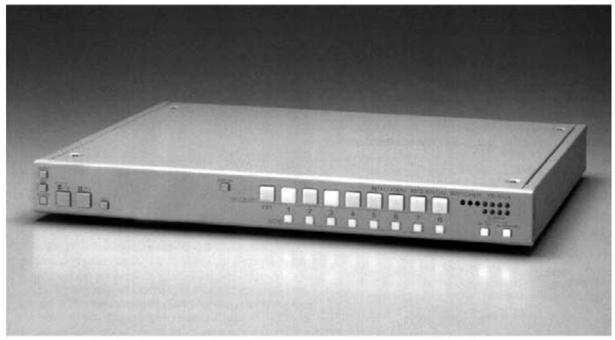


A simple, 8-channel video sequential switcher

The switcher's front panel usually features a set of buttons for each input, and besides the switch position for manual selection of cameras, there is a switch position for including a camera in the sequence or bypassing it. When a sequence is started, the dwell time can be changed, usually by a potentiometer. The most common and practical setting for a dwell time is 2 to 3 seconds. A shorter scanning time is too impractical and eye-disturbing for the operator, while a longer scanning time may result in the loss of information for the nondisplayed cameras. So, in a way, sequential switchers are always a compromise.

Apart from the number of video inputs, sequential switchers can be divided into switchers with and without alarm inputs.

When a sequential switcher has alarm inputs, it means that external normally opened (N/O) or normally closed (N/C) voltage-free contacts can halt the scanning and display the alarmed video signal. Various sources can be used as alarm devices. For indoor applications the choice of suitable sensors is often straightforward, but outdoor alarm sensors are more critical and harder to select. There is no perfect sensor for all applications. The range of site layouts and environmental conditions can vary enormously. The best help you can get in selecting a sensor is from a specialized supplier that has both the knowledge and the experience.



A more advanced switcher

Most common are the ***passive infrared*** (PIR) detectors, door reed switches, PE beams, and ***video motion detectors*** (VMDs). Care should be taken, when designing such systems, about the switcher activity after the alarm goes off – that is, how long the alarmed video input remains displayed; whether it requires manual or automatic reset; if the latter, how many seconds the automatic reset activates for; what happens when a number of alarms activate simultaneously; and so on. The answers to all of these questions are often decisive for the system's efficiency and operation. There is no common answer and it should be checked with the manufacturer's specifications. Even better, test it yourself.

It is not a rule, but quite often simple sequential switchers (i.e., those without alarm inputs) have only one video output. The alarming sequential switchers on the other hand, quite often have two video outputs: one for video sequencing and the other for the alarmed picture. The first output is the one that scans through all the cameras, while the second one is often called the alarmed or spot output because it displays the alarmed picture (when the alarm activates).

Video sequential switchers (or just switchers for short) are the cheapest thing that comes between multiple cameras and a video monitor. This does not mean that more sophisticated sequential switchers are not available. There are models with text insertion (camera identification, time, and date) multiple configuration options via RS-232, RS-485, or RS-422 communications, and so on.

Some models like these either have the power down coaxial cable function, or they send synchronization pulses to the camera via the same cable that brings video signals to the switcher. All this is with the intention of synchronizing cameras, which will be discussed next. Most of these more sophisticated sequential switchers can easily be expanded to the size of a miniature matrix switcher.

Synchronization

One of the more important aspects of switchers, regardless of how many inputs they have, is the switching technique used. Namely, when more than one camera signal is brought to the switcher inputs,

it is natural to have them with various video signal phases. This is a result of the fact that every camera is, in a way, a self-contained oscillator producing the line frequency of the corresponding TV system (i.e., for CCIR 625 × 25 = 15,625 Hz and for EIA 525 × 30 = 15,750 Hz) and it is hard to imagine that half a dozen cameras could have a coincidental phase. This is unlikely even for only two cameras. We call such random phase signals ***nonsynchronized***. When nonsynchronized signals are switched through a sequential switcher, an unwanted effect appears on the monitor screen: ***picture-roll***. A picture-roll appears owing to the discrepancies in the vertical synchronization pulses at various cameras that results in an eye-disturbing picture-roll when the switcher switches from one camera to another. The picture-roll is even more obvious when recording the switched output to a VCR. The roll is more visible with the VCR because the VCR's head needs to mechanically synchronize to the different cameras' vertical sync pulses, while the monitor does it electronically. The only way to successfully combat the rolling effect is to synchronize the sources (i.e., the cameras).

The most proper way of synchronizing cameras is by use of an external ***sync generator*** (***sync-gen***, for short). In such a case, cameras with an external sync input have to be used (please note: not every camera can accept external sync). Various cameras have various sync inputs, but the most common are:

- Horizontal sync pulses (usually known as horizontal drive pulses or HD)
- Vertical sync pulses (usually referred to as vertical drive pulses or VD)
- Composite sync pulses (which include both HD and VD in one signal, usually referred to as composite video sync or CVS)

In order to perform the synchronization, an extra coaxial cable has to be used between the camera and the sync-gen (besides the one for video transmission) and the sync-gen has to have as many outputs as there are cameras in use.



A line-locked camera (24 V AC) which also has an external vertical sync input terminal

This is clearly a very expensive exercise, although, theoretically, it is the most proper way to synchronize. Some camera manufacturers produce models where sync pulses are sent from the switcher to the camera via the same coax that sends the video signal back. The only problem here is the need to have all the equipment of the same make.

There are cheaper ways to resolve the picture-roll problems and one of the most accepted is through ***line-***

locked cameras. Line-locked cameras are either 24 V AC or 240 V AC (110 V AC for the United States, Canada, and Japan) powered cameras. The 50 Hz (60 for the United States, Canada, and Japan) mains frequency is the same as the vertical sync rate, so these cameras (line-locked) are made to pick up the zero crossings of the mains sine wave and the vertical syncs are phased with the mains frequency. If all of the cameras in a system are powered from the same source (the same phase is required), then all of the cameras will be locked to the mains and thus synchronized to each other.

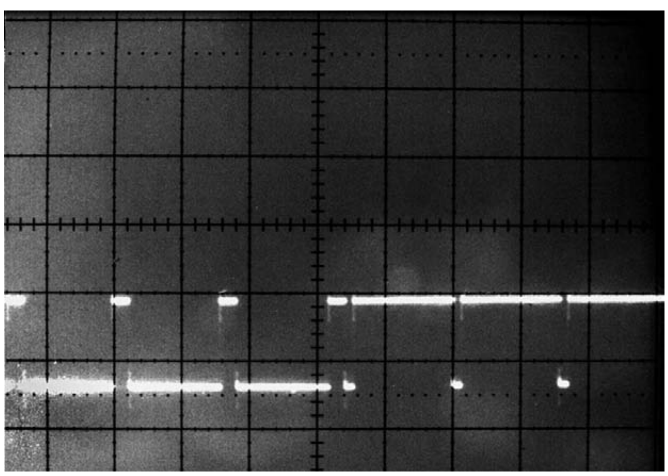
The above method is the cheapest one, although it sometimes offers instability of the mains phase owing to heavy industrial loads that are turned off and on at unpredictable intervals. Still, it is the easiest way. There is even a solution for different phases powering different cameras in the form of the so-called *V-phase* adjustment. This is a potentiometer on the camera body that will allow the camera electronics to cope with up to 120° phase difference. It should be noted that the low-voltage AC-powered cameras (i.e., the 24 V AC) are more popular and more practical than the high voltage ones primarily because they are safer.

Some cameras are designed to accept the video signal of the previous camera and lock to it. This is called ***master-slave*** camera synchronization. By daisy-chaining all of the cameras in such a system, synchronization can be achieved, where one is the master camera and the others are slave cameras. A coaxial cable is required between all of the cameras for this purpose, in addition to the coax for video transmission.

Still, not every sequential switcher can use the benefits of synchronized cameras. The switcher also needs to be a ***vertical interval switcher***. Only vertical interval switchers can switch synchronized signals at the moment of the vertical sync pulse so that the switching is smooth and without roll. Nonvertical interval switchers switch on a random basis rather than at a specific moment relative to the video signals. With the vertical interval switcher, when a dwell time is adjusted to a particular value, the switcher switches with this specific dwell time, but only **when the vertical sync period occurs**. By doing so, **the switching is nice and clean and happens in the vertical blanking period**; that is, there is no picture break on the monitor screen.

Normal switchers, without this design, will switch anywhere in the picture duration; this means it could be in the middle of a picture field. So if the cameras are synchronized, there will be no picture-roll, but picture breaking will still be visible to the operator **owing to the abrupt transition from one signal to another in the middle of the visible picture field**.

The same concept of vertical interval switching applies to the sequential switcher's big brother, the video matrix switcher.

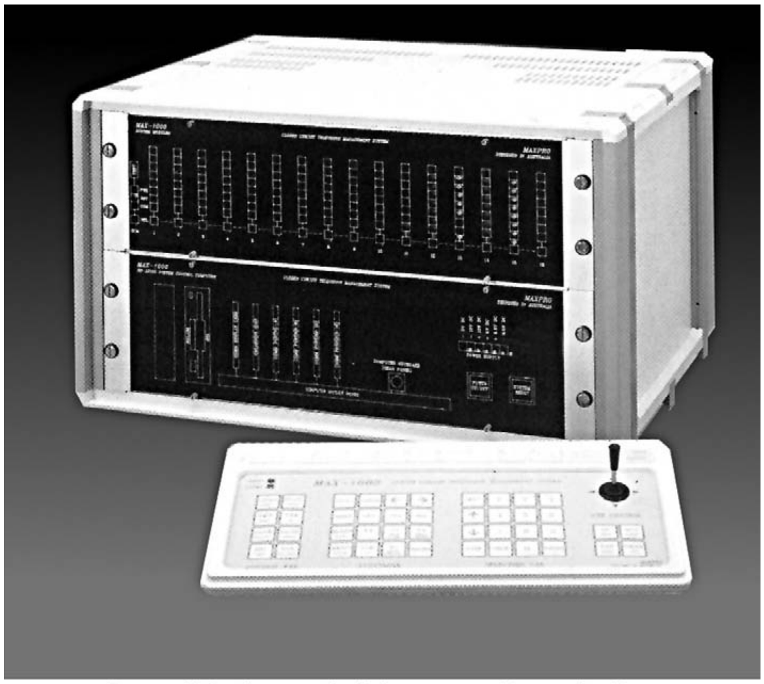


Vertical sync detail

Video matrix switchers (VMSs)

The ***video matrix switcher***, as we have noted, is the big brother of the sequential switcher. The bigger CCTV systems can only be designed with a video matrix switcher (VMS) as the brain of the system.

The name "***matrix switcher***" comes from the fact that the number of video inputs plotted against the number of video outputs makes a matrix, as it is known in mathematics. Quite often, video matrix switchers are called video cross-point switchers. These cross-points are actually electronic switches that select any video input onto any video output at any one time, preserving the video impedance matching. Thus, one video signal can simultaneously be selected on more than one output. Also, more video inputs can be selected on one output; only in this case we would have a sequential switching between more inputs, since it is not possible to have more than one video signal on one output at any single point in time.



A sophisticated video matrix switcher

VMSs are, in essence, big sequential switchers with a number of advancements:

- A VMS can have more than one operator. Remember that the sequential switchers usually have buttons at the front of the unit. Thus, only one operator can effectively control the system at any one time. Matrix switchers can have up to a dozen operators, sometimes even more, all of whom can concurrently control the system. In such a case, every operator controls (usually) one video output channel. A certain intelligent control can be achieved, depending on the VMS in use. Different operators may have equal or different priorities, depending on their position in the security structure of the system.

- The VMS accepts many more video inputs and accommodates for more outputs, as already mentioned, and more importantly, these numbers can easily be expanded at a later date by just adding modules.

- The VMS has pan, tilt, and lens digital controllers (usually referred to as PTZ controllers). The keyboard usually has an integral joystick, or buttons, as control inputs and at the camera end, there is a so-called PTZ site driver (sometimes called PTZ decoder) within a box that is actually part of the VMS. The PTZ site driver talks and listens to the matrix in digital language and drives the pan/tilt head together with the zoom lens and perhaps some other auxiliary device (such as wash/wipe assembly).

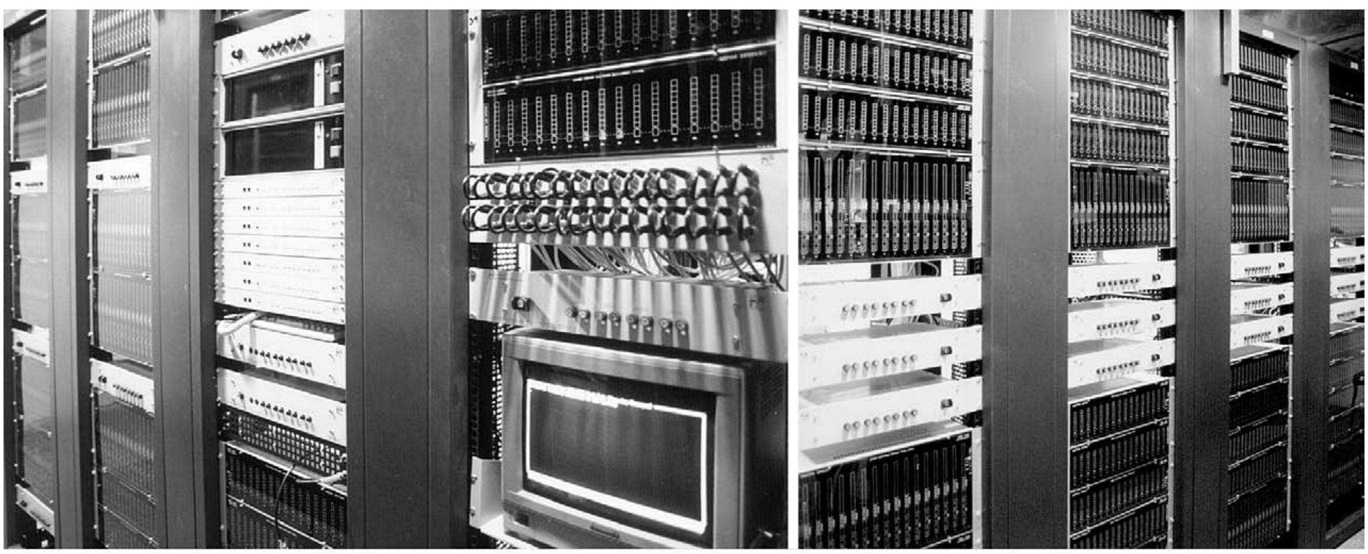
• The VMS generates camera identification, time and date, operator(s) using the system, alarm messages, and similar on screen information, superimposed on the video signal.

• The VMS has plenty of alarm inputs and outputs and can be expanded to virtually any number required. Usually, any combination of alarms, such as N/O, N/C, and logical combinations of them (OR, NOR, AND, NAND), is possible.

• In order for the matrix switchers to perform the very complex task of managing the video and alarm signals, a microprocessor is used as the brain. With the ever-increasing demand for power and processing capacity, microprocessors are becoming cheaper and yet more powerful. These days, full-blown PCs perform these complex processes. As a consequence, a VMS setup becomes programming in itself, complex but with immense power and flexibility, offering password protection for high security, data logging, system testing, and reconfiguring via modem or network. The latest trend is in the form of the graphical user interface (GUI), using popular operating systems, with touch-sensitive screens, graphical site layout representation that can be changed as the site changes, and much more.

• The VMSs might be very complex for the system designer or commissioner, but they are very simple and user friendly for the operator and, more importantly, faster in emergency response.

There are only a handful of manufacturers of VMS in the world, the majority of which come from the United States, England, Denmark, Germany, Japan, and Australia. Many of them have stayed with the traditional concept of cross-point switching and a little bit of programmability, usually stored in a battery-backed EPROM. Earlier concepts with battery-backed EPROMs, without recharging, could only last a few weeks. But many have accepted clever and flexible programming, with the system configuration stored on floppy disks or hard drives, preventing loss of data even if the system is without power for more than a couple of months.



The Maxpro video matrix at Sydney's Star City Casino handles over 1000 cameras and over 800 VCRs.

The demand for compatibility has forced many systems to become PC based, making the operation familiar to the majority of users and at the same time, offering compatibility with many other programs and operating systems that may work in conjunction.



The large Plettac CCTV matrix at Frankfurt Airport

The new designs of matrix switchers take almost every practical detail into account. First of all, configuring a new system, or even reconfiguring an old one, is as easy as entering details through a setup menu. This is, however, protected with high levels of security, which allows only authorized people who know the appropriate access code and procedures to play around with the setup.

Next, the VMS has become so intelligent and powerful that controlling other complex devices has become possible. These include lights in buildings, air conditioning, door access control, boom gates in car parks, power, and other regular operations performed at a certain time of the day or at certain detectable causes.

Unfortunately, there is no standard design or language for configuring and programming matrix switchers. Different manufacturers use different concepts and ideas, so it is very important to choose a proven expert for a particular system.

Matrix switchers usually come with their basic configurations of 16 or 32 video inputs and 2 or 4 video outputs. Other combinations of numbers are possible, but the above mentioned are the most common ones. Many of them come with a certain number of alarm inputs and outputs. Almost all of them, in their basic configuration, have a text insertion feature incorporated and a keyboard for control. A



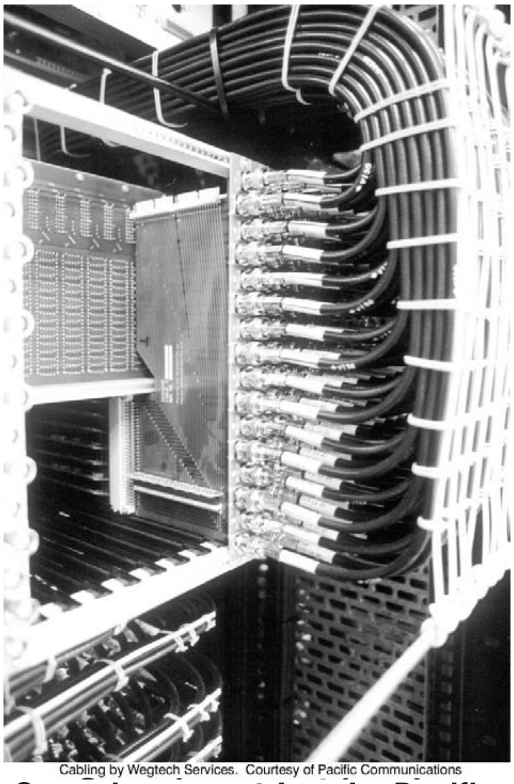
Photo courtesy of Pelco

An intelligent, ergonomic, and reconfigurable matrix keyboard

basic operator's manual and other technical information should be part of the switcher.

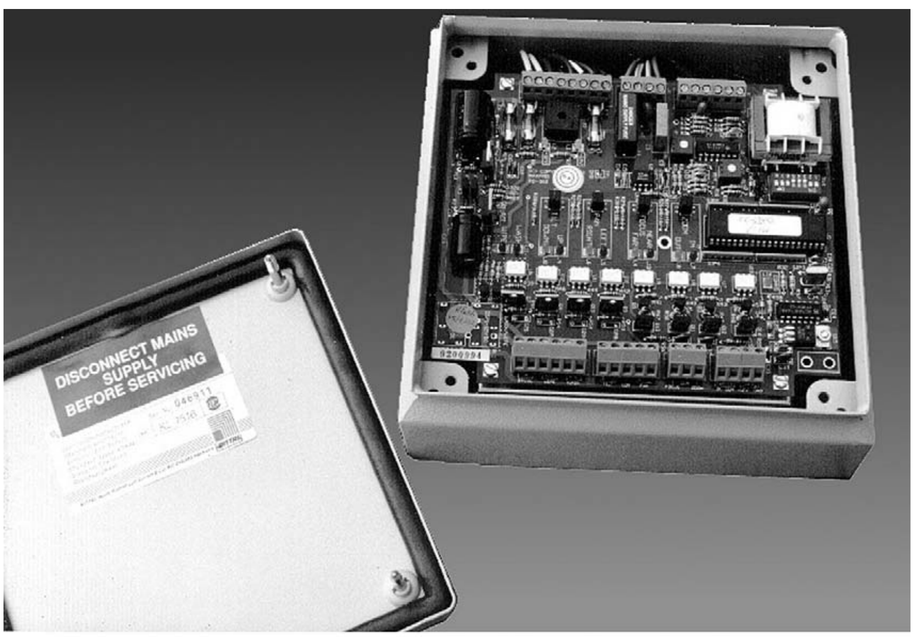
Most suppliers need a separate notice to incorporate PTZ control modules, because in many systems only fixed cameras are used and PTZ control is not considered a must. Some makes, however, may include PTZ control as standard.

The latter does not mean PTZ site drivers will be a compulsory part of the VMS. Since the number of PTZs may vary from system to system, it is expected that the number will be specified when ordering. How many you can actually use in a system depends on the make and model. In most cases, VMS use digital control which has a limited number of sites it can address. This number depends on the controlling distances as well and it can be anything between 1 and 32 PTZ sites. For a higher number of sites, additional PTZ control modules need to be used.



Some larger matrices by Pacific Communications come neatly prewired.

I will repeat again that, until now, there has been no compatibility between products of different manufacturers, so you cannot use, for example, a matrix switcher of one brand and PTZ site drivers of another. In most cases, when a CCTV system with a matrix switcher needs to be upgraded, you need to replace the whole system, with the exception of the cameras, lenses, monitors, and cables. It is fair to say, however, that in the period between the last edition of the book and the present one, an increased number of matrix manufacturers have produced multifunctional driver boards so that you can control at least a couple of different brands. Furthermore, protocol converter boxes are now available that will allow the users, if they know the protocol of the PTZ camera and the matrix switcher, to have them talk to each other.



A typical PTZ site driver (receiver)

Small systems with up to 32 cameras can easily be configured, but when more inputs and outputs are required from a matrix switcher it is better to talk to the manufacturer's

representative and work out exactly what modules are required. This selection can make a big difference between an affordable and an expensive system, as well as between a functional and nonfunctional system.

Because of their capability and potential to do many things other than just video switching, video matrix switchers are often referred to as CCTV management systems. This is not to say that VMS can also perform quad processing or multiplexing of signals. Quad compressors and multiplexers would still be required in addition, if such functions are to be performed.

Switching and processing equipment

Quad compressors

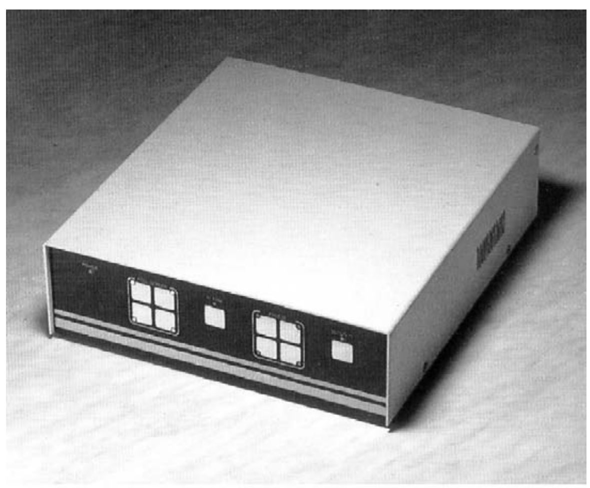
Because of the sequential switchers' inability to view all of the cameras simultaneously and other synchronization worries, the CCTV designers had to come out with a new device called a ***quad compressor***, which is sometimes known as a ***quad splitter***.

Quad compressors, as the name suggests, put up to four cameras on a single screen by dividing the screen into four quadrants (hence the name "***quad***"). In order to do that, video signals are first digitized and then compressed to corresponding quadrants. The quad's electronics does the time base correction, which means all of the signals are synchronized, so when the resultant video signal is produced all of the four quadrants are actually residing on one signal and **there is no need for external synchronization**.

Quad compressors are digital image processing devices with analog input and output.

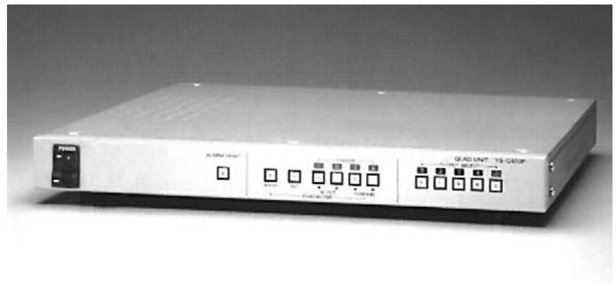
As with any digital image processing device, we should know a few things that define the system quality: framestore resolution expressed by the number of pixels (horizontal × vertical) and the image processing speed.

The typical framestore capacities found in today's quads are 512 × 512 or 1024 × 1024 pixels. The first one is fine compared to the camera resolution, but do not forget that we split these 512 × 512 into four images; hence every quadrant will have 256 × 256 pixel resolution, which might only be acceptable for an average system. So, if you have a choice of quads, you should opt for the higher framestore resolution. Apart from this detail, every pixel stores the gray-level information (monochrome quads) and the color information (color quads). A typical good quality B/W quad will have 256 levels of gray, although 64 levels are sufficient for some. However, 16 levels of gray are too little, and the image appears too digitized. Color



A typical B/W compressor

quads of the highest quality will have over 16 million colors, which corresponds to 256 levels of each of the three primary colors (i.e., 256^3).



A dual-quad compressor

The next important thing about quads is the image processing time. In the early days of quads, the digital electronics were not fast. Quite often you would notice jerky movements, as the quad could only process a few images every second. Slow processing quads are still available today. In order to see smooth movements we need electronics that will process every image at the vertical frequency rate of the TV system (1/50 s or 1/60 s). Then, we will not have motion delays in the picture, and the digitized effect will be less noticeable. We call these fast processing quads *real-time quads*. Real-time and high-resolution quads are more expensive. Color quads are more expensive than monochrome because there is a need for three frame stores for each channel (the three primary colors). If more than four cameras are in the system, the solution can be found in the ***dual quads*,** where up to 8 cameras can be switched onto two quad images alternating one after the other. On most of these quads the dwell time between the two switching quads is adjustable.

Another very handy feature of most quads is the alarm input terminal. Upon receiving an alarm, the corresponding camera is switched from quad mode to a full screen. Usually, this is a live mode; that is, an analog signal is shown without being processed through the framestore. This full-screen alarm activation is especially important when recording. No matter how good the quad video output may look on the monitor, when recorded onto a VHS VCR the resolution is reduced to the limits of the VCR. These limits are (discussed later in the VCR section) 240 TV lines for a color signal and about 300 for B/W. When a quad picture is replayed from the VCR, it is very hard to compare details to what was originally seen in live mode. For this reason, a system can be designed to activate an alarm that will switch from quad to full-screen mode. The details of the activity recorded can then be examined much better. Various things can be used as an activation device, but most often they are passive infrared detectors (PIR), infrared beams, video motion sensors, duress buttons, and reed switches.



Photo courtesy of Gyyr

A quad compressor with alarm inputs

As with alarming sequential switchers, it should be determined what happens after alarm activation – that is, how long the quad stays with the full image and whether or not it requires manual acknowledgment. These are minor details, but they make a big difference in the system design and efficiency.

Sometimes a customer might be happy with quad images recorded as quad, in which case a plain quad, without alarm inputs, might suffice.

However, when full-screen recordings are required, care should be taken in choosing quad compressors that have zoom playback. They may appear the same as the alarming input quads, but in fact they do

not record full-screen images as might be expected. Rather, they electronically blow up the recorded quadrants into a full screen. The resolution of such zoomed images is only a quarter (one-half vertical and one-half horizontal) of what it is after being recorded.

Multiplexers (MUX)

The natural evolution of digital image processing equipment has made video multiplexers a better alternative to quads, especially when recording. Multiplexers are devices that perform ***time division multiplexing*** with video signals on their inputs, and they produce two kinds of video outputs: one for viewing and one for recording.

The output for live viewing shows all of the cameras on a single screen simultaneously. This means, if we have a 9-way multiplexer with 9 cameras, all of them will be shown in a 3 × 3 mosaic of multi-images. The same concept also applies to 4-way multiplexers and 16-way multiplexers. Usually, with the majority of multiplexers, single full-screen cameras can also be selected. While the video output shows these images, the multiplexer's VCR output sends the time division multiplexed images of all the cameras selected for recording. This time division multiplexing looks like a very fast sequential switching, with the difference that all of these are now synchronized to be recorded on a VCR in a sequential manner. Some manufacturers produce multiplexers that only perform fast switching (for the purpose of recording) and full-screen images, but no mosaic display. These devices are called ***frame switchers*** and when recording is concerned they work like multiplexers.

In order to understand this process, we should mention a few things about the VCR recording concept (also discussed later in this book). The video recording heads (usually two of them) are located on a 62 mm rotating drum, which performs a helical scanning of the videotape that passes around the drum. The rotation depends on the TV system: for PAL this is 25 revolutions per second and for NTSC it is 30. By using the two heads, positioned at 180° opposite each other on the video drum, the helical scanning can read or write 50 fields each second for PAL and 60 for NTSC. This means that every TV field (composed of 312.5 lines for PAL and 262.5 for NTSC) is recorded in slanted tracks on the videotape that are densely recorded next to each other. When the VCR plays back the recorded information, it does so with the same speed as the TV standard requires, so we once again reproduce motion pictures.

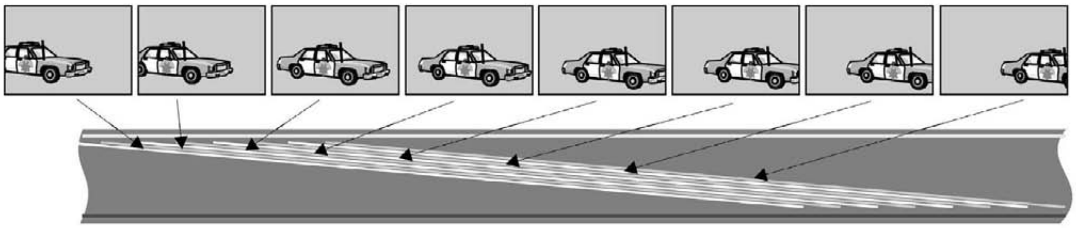
Clearly, however, because the VCR heads are electromechanical devices, the rotation speed precision is critical. Because of the electromechanical inertia, the VCRs have a longer vertical lock response time than monitors. This is the main reason for even bigger picture-roll problems when nonsynchronized cameras are recorded through a sequential switcher.

With normal recordings and playback, the video heads are constantly recording or reading field after field. There are 50 (60 for NTSC) of them every second.

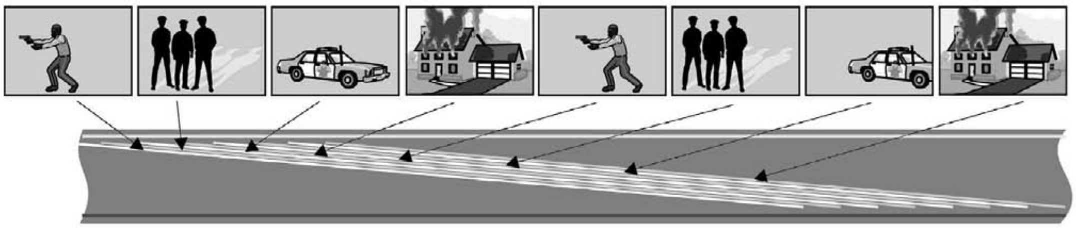


Photo courtesy of Dedicated Micros

Uniplex was one of the first multiplexers.



Real-time recording of a video signal means
50 fields (tracks) for PAL (60 for NTSC) per second of the same signal.



Multiplexed recording of four video signals, for example, means that
50 fields (60 for NTSC), every second, are split among the four.

Explaining the multiplexed recording

Instead of recording one camera a few seconds, then another a few seconds, and so on (which is what a sequential switcher produces), the multiplexer processes video signals in such a way that every next TV field sent to the VCR is another camera (usually the next one in order of inputs).

So, in effect, we have a very fast switching signal coming out of the multiplexer that **switches with the same speed at which the recording heads are recording**. This speed depends on the type of VCR and the recording mode (as is the case with time-lapse VCRs, which will be discussed later in the book). This is why it is very important to set the multiplexer to an output rate suitable for the particular VCR. This selection is available on all multiplexers in their setup menu. If the particular VCR model is not available on your multiplexer, you can either use the generic selection, or if nothing else, use the method of trial and error to find an equivalent VCR. The major difference in TL VCRs is that some are field recorders and others are frame recorders.

Apart from this output synchronization (MUX-VCR), theoretically there is also the need for an input synchronization (cameras-MUX), but because multiplexers are digital image processing devices, this synchronization, that is, the ***time base correction*** (TBC) of the cameras, happens inside the multiplexer. This means that different cameras can be mixed onto a multiplexer and there is no need for them to be gen-locked (i.e., synchronized between themselves).



Photo courtesy of Dedicated Micros

An 8-channel multiplexer

Some multiplexer models on the market, however, are made to synchronize the cameras by sending sync pulses via the same coaxial cable that brings the video signal back and then multiplex the synchronized cameras. These multiplexers do not waste time on TBC and, therefore, are supposed to be faster.

When playback is needed, the VCR video output goes first to the multiplexer, and then the multiplexer extracts the selected camera only and sends it to the monitor. The multiplexer can display any one camera in full screen, or play back all of the recorded cameras in the mosaic mode (multiple images on one screen).



Photo courtesy of Gyyr

16-input looping multiplexer

Recording time delays

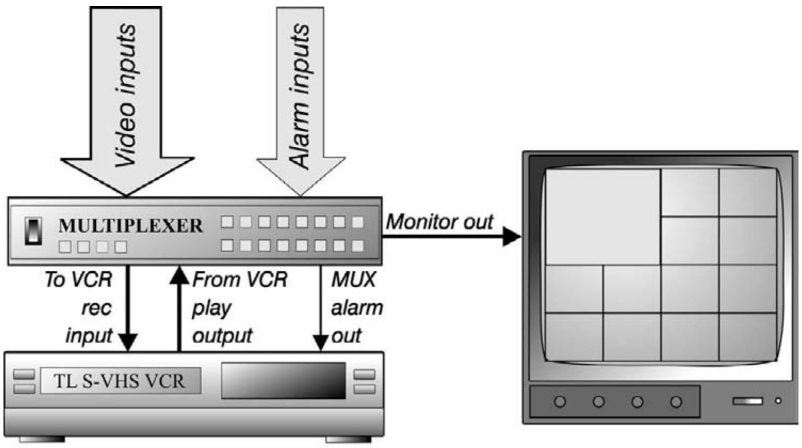
The number of shots (images) taken from every camera during the recording depends on the total number of cameras connected to the multiplexer and the time-lapse mode of the VCR. Therefore, **it is not possible to record real-time images from all the cameras simultaneously** because, as the name suggests, this is a time division multiplexing.

There are, however, ways to improve performance by using external alarm triggers, usually with a built-in activity detector (to be explained later) in the multiplexer. The best way, though, is to record in as short a time-lapse mode as is practically possible and also to keep the number of cameras as low as possible. Translated into plain language, if your customer can change tapes at least once a day, do not use more than a 24-hr time-lapse recording mode. If the system is unattended over weekends, then a 72-hr time-lapse mode should be selected. And, if the budget allows, instead of using a 16-way multiplexer for more than 9 cameras, it would be better to use two 9-way (some manufacturers have 8-way and some 10-way) multiplexers and two VCRs. The recording frequency will then be doubled, and two tapes will need to be used instead of one.

This is how you can calculate the time gaps between the subsequent shots of each camera. Let us say we have a time-lapse VCR that records in 24-hr time-lapse mode. Earlier we stated stated normal (real-time) recording VCRs make 50 shots every second in PAL and 60 in NTSC. If you open the TL VCR technical manual, you will find that when the VCR is in 24-hr mode it makes a shot every 0.16 s and even if you do not have a manual with the VCR, it is easy to calculate: When a PAL VCR records in real time, it makes a field recording every $1/50 = 0.02$ s. If the TL VCR is in 24-hr time-lapse mode, it means $24 \div 3 = 8$ times slower recording frequency. If we multiply 0.02 with 8 we get 0.16 s. The same exercise for NTSC VCR will obtain a field recording every $1/60 = 0.0167$ s. For a 24-hr time-lapse mode, when using T120 tape, $24 \div 2 = 12$. This means that in 24-hr time-lapse mode in the NTSC format, the TL VCR moves 12 times slower to fit 24 hr on one 2-hr tape. Thus, the update rate of each recorded field in 24-hr mode is $12 \times 0.0167 = 0.2$ s.

All of these calculations refer to a single camera signal; therefore, if the multiplexer has only one camera, it will make a shot every 0.16 s in PAL and every 0.2 s in NTSC. If more cameras are in the system,

in order to calculate the refresh rate of each camera, we need to multiply by the number of cameras, plus add a fraction of the time the multiplexer spends on time base correction due to nonsynchronized cameras (which will usually be the case). So if we have, for example, 8 cameras to record, 8 × 0.16 = 1.28 s (PAL) and 8 × 0.2 = 1.6 s (NTSC). Adding to it the time spent on sync correction and the realistic time gaps between the subsequent shots of **each** camera should result in approximately 1.5 to 2 s. This is not a bad figure when considering that **all 8 cameras are recorded on a single tape**. If we have to identify an important event that happened at 3:00 P.M., for example, we can either view all of the cameras in a mosaic mode and see which cameras have important activity, or we can select each one of them separately in full screen.



A typical multiplexer – TL VCR interconnection

For some applications, 2 s might be too long a time to waste; this is where the alarm input or the motion activity detection can be very handy. Most of the multiplexers have alarm input terminals and with this we can trigger the **priority encoding** mode. **The priority encoding mode is when the multiplexer encodes the alarmed camera on a priority basis**. Say we have an alarm associated with camera 3. Instead of the normal time division multiplexing of the 8 cameras in sequence 1, 2, 3, 4, 5, 6, 7, 8, 1, 2, it goes 1, 3, 2, 3, 4, 3, 5, 3, 6, 3 and so on. The time gap in such a case is prolonged for all cameras other than 3. But since number 3 is the important camera at that point in time, the priority encoding has made camera 3 appear with new shots every 2 × 0.16 = 0.32 s, or in practice almost 0.5 s (due to the time base correction). This is a much better response than the previously calculated 2 s for the plain multiplexed encoding. It should be noted, however, when more than one alarm is presented to the multiplexer inputs the time gaps between the subsequent camera shots are prolonged, and once we get through all of the alarmed camera inputs, we get plain multiplexed encoding.

In case a system cannot be designed to use external alarm triggers, it should be known that most of the multiplexers have an ***activity motion detection*** built in. This is a very handy feature in which every channel of the multiplexer analyzes the changes in the video information in each of the framestore updates. When there is a change in them (i.e., something is moving in the field of view), they will set off an internal alarm, which in turn will start the priority encoding scheme. This feature can be of great assistance when replaying intrusions, or events, and determining the activity details.



A typical multiplexer display

Usually, the activity motion detection can be turned on or off. When turned on, on some MUX models, it will allow you to configure the shape of the detection area in order to suit various areas or objects.

Real-time time-lapse recorders have appeared on the CCTV market that might confuse the issue of calculating the refresh rate. These are faster recording machines where the TL VCR's mechanics is modified so as to record 16.7 fields per second in PAL (a field every 0.06 s) for 24-hr relative to E240 tape. In the case of NTSC, around 20 fields per second (a field every 0.05 s) can be recorded for 24 hrs on a T160 tape. Understandably, to calculate the refresh rate of multiplexed cameras on such a TL VCR, you would need to multiply the number of cameras with the above-mentioned field update.

If we wanted to be fair, this is not actually real-time recording, but it is definitely better than the ordinary time-lapse mode. To the best of my knowledge only one CCTV manufacturer – Elbex – makes real 24-hr recordings at 50 fields per second for PAL and 60 for NTSC.

The NTSC system uses tape at a higher recording speed (2 meters/minute) than PAL or SECAM (1.42 meters/minute). To confuse this issue even more, VHS tapes are marked in playing times as opposed to tape length. Therefore, a T120 (2-hr) tape bought in the United States is not the same as an E120 (2-hr) tape bought in the UK. The U.S. T120 tape is 246 meters in length and will give 2 hours of play time on an NTSC VCR. This same tape used on a PAL VCR will give 2 hours and 49 minutes of play time. Conversely, a UK E120 tape is 173 meters in length and will give 2 hours of play time on a PAL VCR. The same tape used on an NTSC VCR will give only 1 hour and 26 minutes of play time. The following chart compares the recording times of each tape in SECAM, NTSC and PAL.

Tape label	*Tape length (m)*	*NTSC time (min)*	*PAL time (min)*
E30	*45*	*22*	*30*
E60	*88*	*44*	*60*
E90	*130*	*65*	*90*
E120	*173*	*86*	*120*
E180	*258*	*129*	*180*
E240	*346*	*173*	*240*
T20	*44*	*20*	*28*
T30	*64*	*30*	*42*
T45	*94*	*45*	*63*
T60	*125*	*60*	*84*
T90	*185*	*90*	*126*
T120	*246*	*120*	*169*
T160	*326*	*160*	*225*

Simplex and duplex multiplexers

Most multiplexers will allow you to view images of any selected camera in a mosaic mode while they are encoding. When a recorded tape needs to be viewed, as we have already mentioned, the VCR output does not go directly to a monitor, but it has to go through the multiplexer again in order for the images to be decoded. While doing this, the multiplexer cannot be used for recording. So, if recording is very important and the playback needs to be used in the meantime, another multiplexer and VCR are required. Multiplexers that can do only one thing at a time are called ***simplex multiplexers***.

There are also ***duplex multiplexers***, which are actually two multiplexers in the one unit, one for recording and one for playback. Still, two VCRs will be required if both recording and playback are required at the same time.

Some manufacturers even make multiplexers, which they refer to as *triplex*. These are multiplexers with the same functionality as the duplex ones, with the addition of displaying a mixture of live and playback images on one monitor.

As with quad compressors, we can get B/W and color multiplexers. We also have a limited amount of framestore resolution available. Needless to say, the bottleneck in the resolution reproduction will still be the VCR itself. Many newer CCTV systems are being installed with Super VHS VCRs that offer an improved resolution of 400 TV lines as opposed to 240 with the ordinary VHS format.

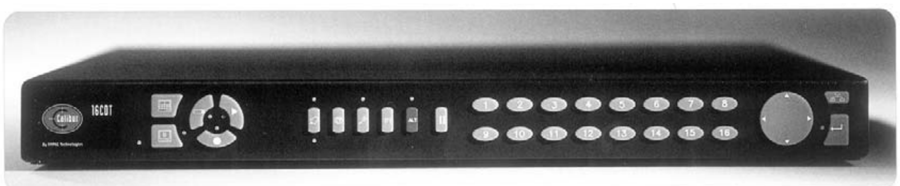


Photo courtesy by Calibur

A 16-channel triplex multiplexer

Multiplexers can successfully be used in applications other than just recording. This might be especially useful if more than one video signal needs to be transmitted over a microwave link, for example. By using two identical simplex multiplexers, one at each end of the link, we can transmit more than one image in a time division multiplexed mode. In this instance, the speed of the refresh rate for each camera is identical to what it would be if we were to record those cameras in real (3-hr) mode on a VCR.

Video motion detectors (VMDs)

A ***video motion detector*** (VMD) is a device that analyzes the video signal at its input and determines whether its contents have changed. Consequently, it produces an alarm output.

With the ever-evolving image processing technology, it became possible to store and process images in a very short period of time. If this processing time is equal to or smaller than 1/50 (PAL) or 1/60 (NTSC), which as we know, is the live video refresh rate, we can process images without losing any fields and preserve the real-time motion appearance.

In the very beginning of the development of VMDs, only analog processing was possible. Those simple VMDs are still available and perhaps still very efficient relative to their price, although they are incapable of sophisticated analysis; therefore, high rates of false alarms are present. The principles of operation of the analog VMDs (sometimes called video motion sensors) are very simple: a video signal taken from a camera is fed into the VMD and then onto a monitor, or whatever switching device might be used. In the analyzed video picture, little square marks (usually four) are positioned by means of a few potentiometers on the front of the VMD unit. The square marks actually indicate the sensor areas of the picture and the video level is determined by the VMD's electronics. As soon as this level is changed to a lower or higher value, by means of someone or something entering the field of view at the marked area, an alarm is produced. The sensitivity is determined by the amount of video luminance level change required to raise an alarm (usually 10% or more of the peak video signal). The alarm is usually audible, and the VMD produces relay closure, which can be used to further trigger other devices. The alarm acknowledgment can be either automatic (after a few seconds) or manual. There is also a VMD sensitivity potentiometer on the front panel in such devices, and with the proper adjustment it can bring satisfactory results. There will always be false alarms activated by trees swaying in the wind, cats walking around, or light reflections, but at least the reason for the alarm can be seen when the VCR is played back (assuming the VMD is connected to a VCR).



A simple non intelligent single-channel video motion detection unit



A PC-based VMD system by Dindima

VMDs are often a better solution than passive infrared motion detectors (PIR), not only because the cause of the alarm can be seen, but also because it analyzes exactly what the camera sees, no less and no more. When using a PIR, its angle of coverage has to match the camera's angle of view if an efficient system is to be achieved.

When a number of cameras are used, we cannot switch signals through the VMD because it will cause constant

alarms; therefore, one VMD is required per camera. In systems where further processing of the video signal is done, the sensing markers can be made invisible, but they are still active.

The next step up in VMD technology is the digital video motion detector (DVMD), which is becoming even more sophisticated and popular. This, of course, is associated with higher price, but the reliability is also much higher and the false alarm rate is lower.

One of the major differences between various DVMD manufacturers is the software algorithm and how motion is processed. These concepts have evolved to the stage where tree movement due to wind can be ignored, and car movement in the picture background can also be discriminated against and excluded from the process deciding about the alarm activity. In the last few years, DVMDs that take the perspective into account have been developed. This means that as the objects move away from the camera, thus getting smaller in size, the VMD sensitivity increases in order to compensate for the object's size reduction owing to the perspective effect. This effect, we should point out, also depends on the lens.

Many companies now produce a cheaper alternative to a full-blown stand-alone system in a form of PC card(s). The cards come with specialized software, and almost any PC can be used for VMD. Furthermore, image snapshots can be stored on a hard disk and transmitted over telephone lines connected to the PC. With many options available in the VMDs, a lot of time needs to be spent on a proper setup, but the reward will be a much more reliable operation with fewer false alarms.

A special method of recording, called ***pre-alarm history***, is becoming very standard in most of the VMD devices. The idea behind this is very simple but extremely useful in CCTV. When an alarm triggers the VMD, the device keeps a number of images recorded after the alarm occurrence, but also a few of them before. The result is a progressive sequence of images showing not only the alarm itself, but also what preceded it.

One of the latest developments in this area has brought to light an Australian company, among a few other successes, with their (original) concept of three-dimensional video motion detection. This concept offers extremely low rates of false alarms by using two or more cameras to view objects from different angles. Thus, a three dimensional volumetric protection area is defined, which like the



Photo courtesy of Practel

PC-based 3-dimensional VMD by Practel

other VMDs is invisible to the public, but it is quite distinguishable to the image processing electronics. With this concept, movement in front of any of the cameras will not trigger an alarm until the **protected volume area**, as seen by **both cameras**, is disturbed. Using this concept, valuable artworks in galleries, for example, can be monitored so that the alarm does not activate every time someone passes in front of the artwork, but only when the artwork is removed from its position.

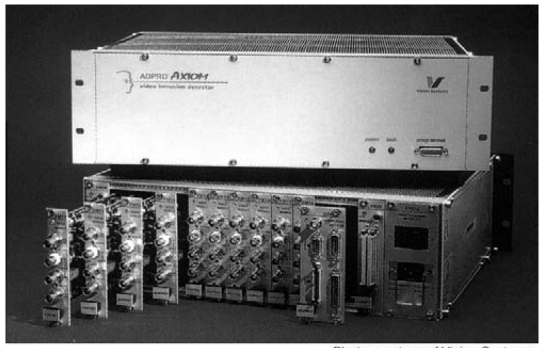


Photo courtesy of Vision Systems

A sophisticated multi channel video motion detection unit

Quite often, alarm detection is useful not when someone or something moves in the field of view, but rather when something fixed is removed from its location. This can be done with a ***video nonmotion detector*** (VNMD). This unit is very similar to the VMD, except that additional information is collected for objects put in the field of view that are stationary for a longer period. Movements around the **selected** object cause alarms only when the protected object is removed from the stationary position.

In the last couple of years, some modern DSP cameras have offered VMD circuitry built inside the camera itself. This could be quite practical in systems where recording and/or an alarm is initiated only when a person or object moves inside the camera's field of view.

All of the above-mentioned VMDs, used as an alarm output, produce a closure of relay contacts that can trigger additional devices in the CCTV chain, like VCRs, or matrix switchers, framestores, sirens, or similar. If you decide to use one, make sure you clarify the type of alarm output with the supplier, for it can be anything from voltage-free N/O contacts to a logic level voltage (5 V) N/C output.

We should also mention VMDs that, apart from the motion detection, also dial remote receiving stations and send images via telephone lines. With such devices, remote monitoring is possible from virtually anywhere in the world. Images are sent to a receiver station only when the VMD detects movement, indirectly saving on long-distance telephone calls.

Framestores

Framestores are, conceptually, very simple electronic devices used to temporarily store images. Two important parts of a framestore device are the analog-to-digital (A/D) conversion (ADC) section and the random access memory (RAM) section. The ADC section converts the analog video signal into digital, which is then stored in the RAM memory, for as long as it is powered.

The main advantage of the framestores compared to VCRs is their response time. Since they do not have any mechanically moving parts, the storage of the alarmed picture is instant on activation. This is then fed back, usually, to a video printer or a monitor for viewing or verification purposes.

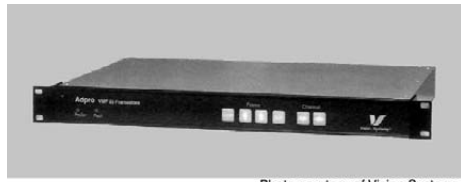


Photo courtesy of Vision Systems

A framestore device

More sophisticated framestores are usually designed to have a few framestore pages that constantly store and discard a series of images using the first in first out (FIFO) principle until an alarm activates. When that happens, it is possible to view not only the alarmed moment itself, but also a few frames taken before the alarm event took place, thereby giving a short event history. This is the same concept as the "***pre-alarm history***" used in VMDs.

Another application of the framestores is the ***frame locking device***. This device constantly processes video signals present at its input and also does the time base correction to be in sync with the master clock inside. Since this processing takes place at a very fast real-time rate and the framestore has a high resolution, there is no perceptible degradation of the video signal. This is a very practical and useful device for showing (switching) nonsynchronized cameras on a single monitor. In such cases, the frame lock device acts as a synchronizer (i.e., it eliminates picture-roll while cameras are scanning).

The major division of framestores, as used in CCTV, is into B/W and color. The quality of a framestore is determined, first, with the framestore resolution, that is, the number of pixels that can be stored and second, with the gray level's bit resolution or, in the case of color, the number of bits used to store colors. A typical good-quality framestore has more than 400 × 400 pixels, and the usual resolution is 752 × 480 pixels and 256 levels of gray (2^8). For a color framestore (with three color channels) we would have over 16 million colors (256 × 256 × 256).

Video printers

Video printers are commonly used in larger systems where a hard-copy printout of a live or recorded image is necessary for evaluation or evidence. There are two types of video printers: monochrome and color. The monochrome video printers usually use thermal paper as an output medium, but some more expensive ones can print on plain paper. The thermal-paper video printers, used for monochrome signals, are similar in operation to the facsimile machine, and they print out images with a size and resolution dependent on the printer's resolution. With thermal printers the output is not as durable and stable (due to thermal paper aging), and the printouts need to be photocopied for longer duration.

Color video printers print on special paper, and the process of printing is similar to dye-sublimation printing, using cyan, magenta, yellow, and black filters. The printing quality produced by such technology is excellent, but the



Photo courtesy of Panasonic

A color video printer

number of copies that can be produced is limited; the cartridge needs to be replaced with every new set of paper.

More sophisticated video printers have a number of controls, including titling, sharpening, duplication into more copies, and storing the images in their framestores until a printout is necessary. In many instances, CCTV users do not want to invest in a video printer, so often there is the need to use the specialized services of some bureaus. The videotape is taken to them and the certain event(s) is/are extracted and printed out.

In many instances, CCTV users do not want to invest in a video printer, so often there is the need to use the specialized services of some bureaus. The videotape is taken to them, and the certain event(s) is/are extracted and printed out.



8. Analog video recorders

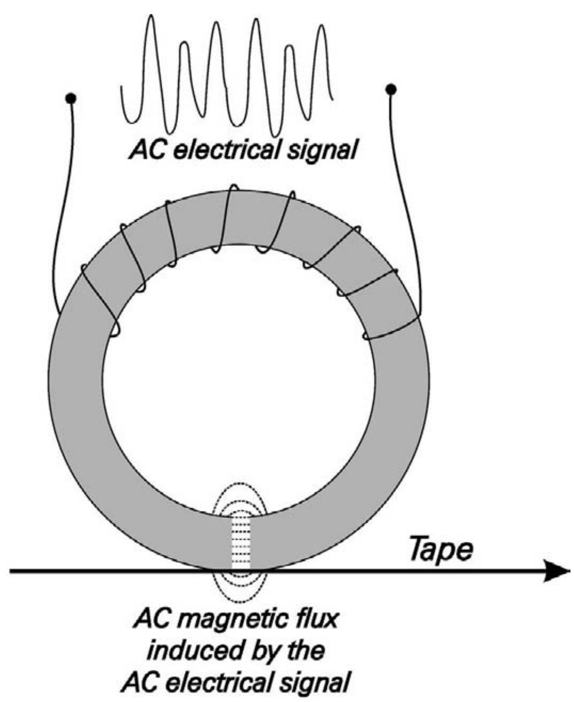
Video recorders were very important in CCTV until a few years ago, but since the introduction of the digital video recorder (DVR), systems sold with VCRs can be counted on one's hands. It is fair, however, for the sake of the good old times, to reproduce this whole chapter on VCRs in this edition of the book, just in case you come across an existing system and you want to know a little bit more about it. Special attention is given to ***time-lapse VCR*** technology, which was a predecessor to the ***DVR***.

A little bit of history and the basic concept

The era of tape recording began in 1935 with the appearance of AEG's first commercial sound tape recorder, called the ***Magnetophone***. The tape used was a cellulose acetate tape, coated with carbonyl iron powder. The performance of these sound recording machines, even though it was very good for its time, steadily improved during the 1930s and 1940s, to the point where at the end of the 1940s much of the radio broadcast material was off tape and indistinguishable from live programs.

The basics of magnetic tape recording are familiar to most of us from the old audio cassette recorders. An alternate current (AC) signal, passing through an audio head winding, produces alternate magnetic flux through a magnetically permeable metal ring, called a head. In order for the magnetic flux to come out of the ring (otherwise, the magnetic flux will stay inside the core), a little slit is made at one end of the core. This slit will now act as an exhaust for the magnetic field that exits the core and closes it through the air going back to the other end of the slit. But if we put a magnetic tape very close to the head, the flux will pass through the tape itself, thus closing the circle. The magnetic tape is a very thin tape coated with magnetic powder, whose microscopic particles act as little magnets. By applying an external magnetic field, these little particles can be polarized in various directions, depending on the current intensity and its direction.

If the magnetic tape is stationary, no information will be recorded, except for the last state of the magnetic field. In order for an audio recording to be performed, **the tape needs to move at a constant speed**. At what speed, depends on the resolution, that is, the highest frequency needed to be recorded. **The faster the tape moves and the smaller the gap in the ring is, the higher the frequency can be recorded.**



The concept of magnetic recording

An analogy to the above would be like having a fountain pen with a sharp tip and another one with a calligraphic tip. With the sharper tip we can write more

details and smaller fonts, on the same space, than with the calligraphic tip.

This is a simplified description of how audio recording is done. In real life, the audio signal is not recorded directly as it is, rather it is amplitude modulated with a sine wave. It has been found that the linearity of the recorded signals is then better. The tape speed, in the case of an audio cassette, was chosen to be 4.75 cm/s. So, a half-hour recording made on one side of a C-60 cassette will take about 86 m (4.75 × 60 × 30 = 8550 cm) of tape. With a good-quality tape an audio bandwidth of approximately 50 Hz to 15,000 Hz can be recorded with a clean head. With such audio characteristics, the recording is not impressive when compared to today's digital CD standards. Obviously, with bigger audio tape recorders (reel-to-reel) and a quadrupled tape speed of 19 cm/s, the recorded and reproduced bandwidth is much better.

A similar concept to audio tape recording was initially tried on video signals, back in the 1950s, when strange machines were designed with tape speeds close to 1000 cm/s and extraordinarily big reels. The theory behind the tape recording showed that in order to record a monochrome video signal with a bandwidth of only 3 MHz (for a reasonable picture quality, as opposed to only 15 kHz in audio), a tape speed of around 3 m/s (300 cm/s) is required. For such a speed, one can calculate that for only a one-hour recording, 3 × 60 × 60 = 10,800 m of tape is required. The quality of such a ***longitudinal*** recording was still very poor and the equipment extremely large and difficult to deal with.

Knowing the size of a C-60 tape (86 m), one can imagine the physical size of reels having 10 km of tape. Since this was very impractical, a solution was sought for in a different way of achieving the tape speed relative to the video head. In the 1950s, a couple of Ampex™ engineers came up with a ***transverse-scan*** system that had 4 video heads rotating while the tape passed at an incredible speed of 40 m/s. This system was capable of recording up to 15 MHz of signal bandwidth and was sufficient in quality for broadcast television. For the commercial and CCTV markets this product was far too expensive, so other alternatives and solutions had to be developed.

The early VCR concepts

By the end of the 1950s, the concept of ***helical scanning*** was proposed. This was a much simpler system than transverse scanning, although initially all of the manufacturers offered open reel designs, incompatible with each other. The recorders were not using cassettes yet and were not for domestic use.

In the 1970s, Sony™ proposed its ***U-matic*** standard, which became well established in the broadcast industry, having very good performance for its time and introducing cassettes instead of open reels.



An early model VHS VCR

It was 1972 when Philips™ came out with its first machine aimed at the domestic market called N1500, which was a real milestone in VCR development. Unfortunately, however, it did not sell very well. It offered one hour of recording and had a

built-in tuner, timer, and RF modulator. This led to the development of the ***System 2000*** design, but unfortunately it happened at the time when color television appeared and a lot of people were saving money to buy color TVs instead of VCRs.

In the early 1970s, Matsushita™ and JVC™ came out with their rival proposals, – the ***video home system (VHS)***, while Sony™ proposed the ***Beta***. So there was actually a bitter competition between the System 2000, Beta, and VHS. They were similar in concept but unfortunately, totally incompatible.

In time, VHS became the most popular and widely accepted by the domestic market. Technically speaking, VHS was initially the poorest in quality, but it was much simpler and cheaper to make.

Over the years, a lot of improvements have been made in VHS making it a much better quality product than it was originally, so that today in CCTV, as is the case with the domestic market, VHS is used in more than 90% of cases. Once VHS was widely accepted, Sony came out with its ***8 mm*** format and then its ***Hi 8 mm***, offering much smaller tapes and better recording quality, but JVC™ released its ***Super VHS***, which matched the Hi 8 quality.

As we have already mentioned, a special type of VHS VCR was developed for CCTV, called a ***time-lapse VCR***. That is why in this book we will only cover the VHS concept. We are perhaps being a little bit unfair to the other formats that may also be in use, like the U-Matic, Beta, or 8, but time and space allows us only to concentrate on the equipment used in the majority of systems today.

The video home system (VHS) concept

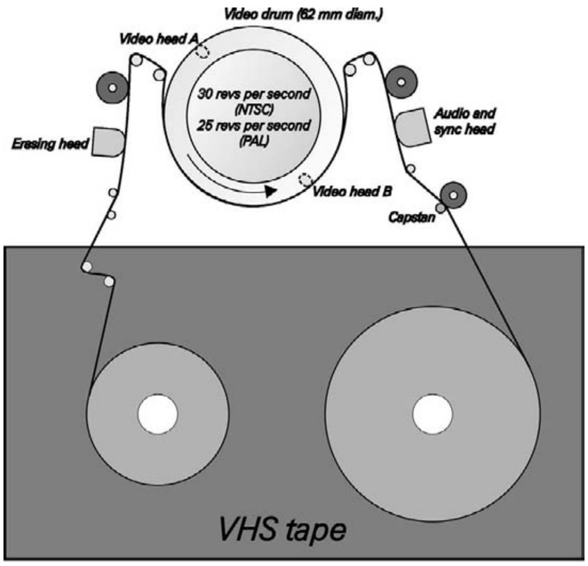
In helical scanning, the heads are located on a tilted drum that rotates with a speed equal to the video frame frequency, 25 revolutions per second for PAL and 30 for NTSC. **The required tape-relative-to-head speed is achieved mainly with the head drum rotation.**

With the initial video home system (VHS) design actually two video heads were used, 180° opposite each other. They are mounted on a rotating cylinder called a ***video drum***. So when a recording or playback happens, each head records or plays back one TV field. The videotape is wound around the drum for 180°; thus, **one of the two video heads is always in contact with the tape**. The actual speed of the tape relative to the stationary parts of the VCR's tape compartment is 2.339 cm/s (PAL) – that is approximately half the speed of an audio cassette. For NTSC speed is a bit higher, 3.33 cm/s.



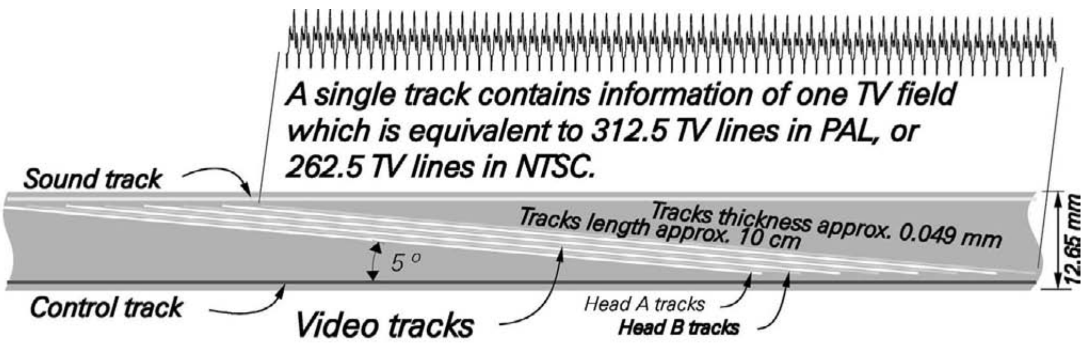
A VHS video drum with two video heads

The VHS tape format is 1/2" (12.65 mm) wide, and as can be seen from the drawing below, the thickness of each of the slanted tracks is approximately 0.049 mm and their length is approximately 10 cm. In so little space, information for 312.5 lines for PAL (and 262.5 for NTSC) has to be recorded. When you have this in mind, it becomes understandable how important the quality of the tape is, both with its magnetic coating and its mechanical continuity and durability.



The VHS tape alignment

Apart from the video signal, which is recorded on slanted tracks, audio is also recorded on the tape, with a stationary audio head on the top part of the tape and control tracks on the bottom.

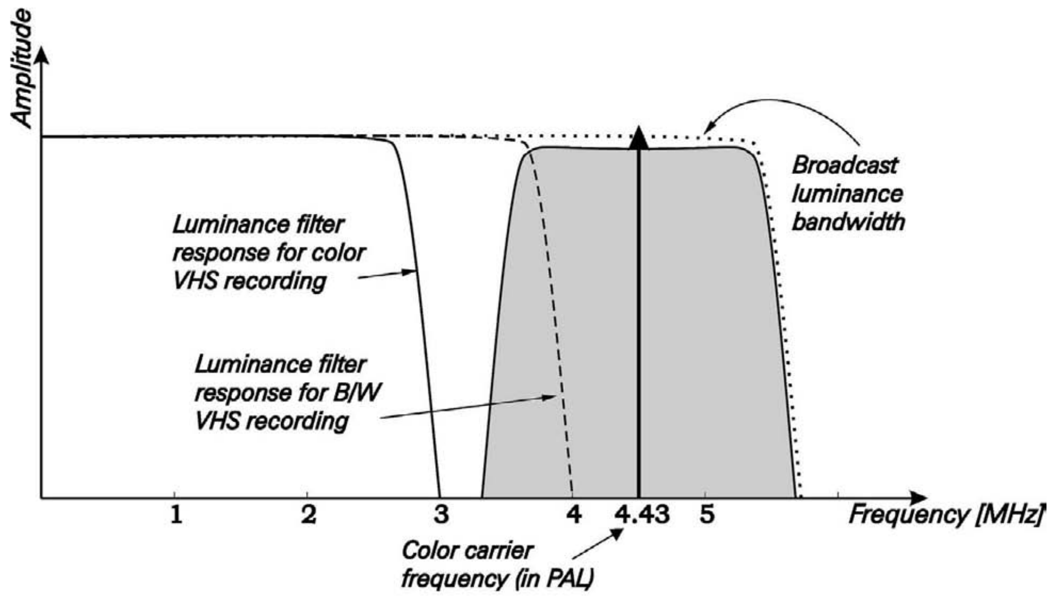


1:1 scaled and simplified drawing of a VHS tape and recording

Certain limitations are imposed on the video signal when it gets inside the VCR electronics. For starters, the design of the VHS recording, including the size of the video drum, the rotation speed, and the videotape quality, determine how wide a bandwidth can be recorded on the videotape.

When the video signal gets to the video input stage of the VCR, it goes through a very sharp-edged low-pass filter with a high-frequency end of 3 MHz. This filter passes only the luminance information, while the chrominance is extracted from the high-pass filtered portion of the same signal. The reason for such a cutoff of the luminance is simply that more cannot be recorded. Those are the limits of the VHS concept.

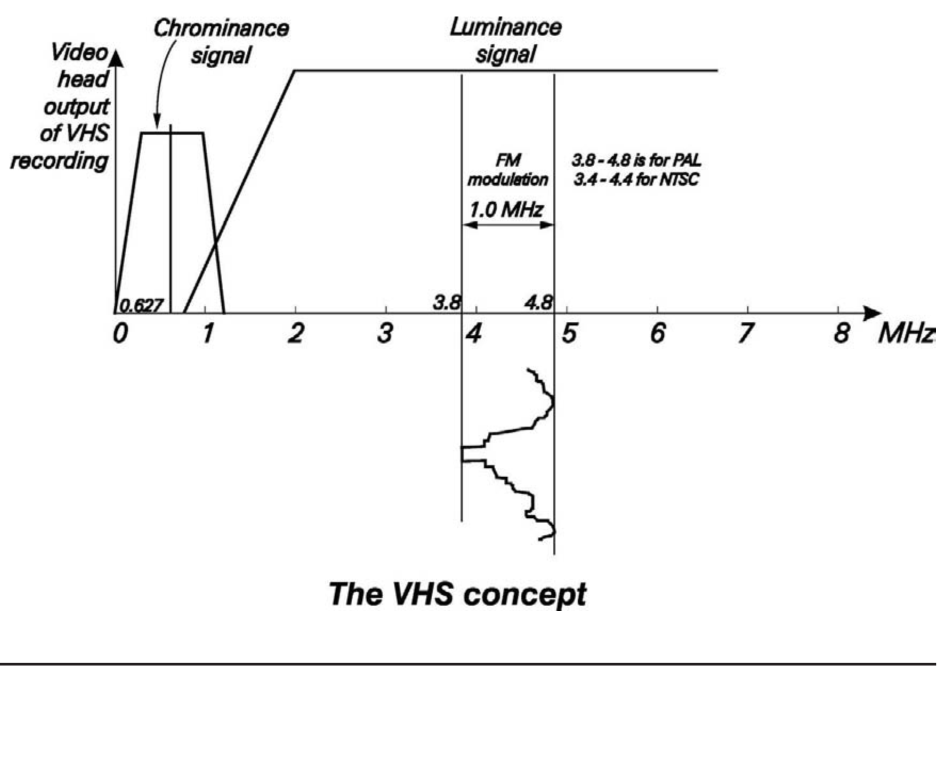
From the simple relation we introduced earlier, 3 MHz corresponds to 240 TV lines of horizontal resolution. This is the practical limitation for a color video signal when played back. This indicates that the VCR is almost always the bottleneck in achieving a good-quality playback picture in today's CCTV systems.



Composite video signal

When recording only monochrome signals, the low-pass filtering can be bypassed since we do not have a color carrier. In such cases, the actual resolution will be a bit higher and depending on the tape and VCR quality, it can be close to 300 TV lines. Many VCRs have an automatic switch for this bypass, but on most time-lapse VCRs there is a manual switch for it.

The actual video luminance signal is not recorded directly as it is, but it is modulated, as is the case with the audio recording. In VHS, the luminance is frequency modulated (FM) with frequency deviations starting from 3.8 MHz (corresponds to lowest sync peak) up to 4.8 MHz (corresponds to white peaks). The chrominance information, which is extracted from the VCR input, is directly recorded with a down-converted



The VHS concept

carrier of 627 kHz and occupies the 0 ~ 1 MHz spectrum range. This is possible because the luminance is frequency modulated above this area.

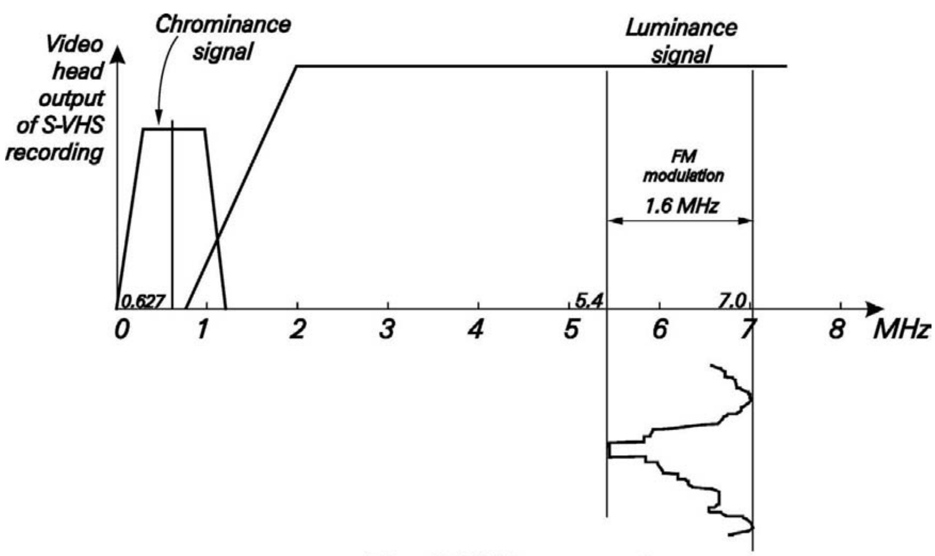
With the further development of the VHS concept a lot of improvements were introduced. Models with four heads were produced, long play mode was offered, and pause mode stability improved considerably. Also, audio recording, which was initially very poor with low-speed transversal recording, was improved in the Hi-Fi models. Instead of the initial 40 Hz ~ 12 kHz audio bandwidth, a high fidelity sound is recorded with audio heads located on the video drum itself, rotating with the same speed as the video heads. With such a high-speed tape-relative-to-heads recording, the audio bandwidth was widened to 20 Hz–20 kHz and the signal/noise ratio dramatically increased from 44 dB to over 90 dB. The Hi-Fi audio channels are not recorded on separate tracks along the video but rather in the deeper layer of the tape and with a different azimuth angle of the recorded FM signal. This type of recording is therefore called ***depth multiplex recording***.

Even though better tapes and video heads were manufactured, the video bandwidth could not be improved considerably, owing to the limitations of the concept itself. Having this in mind, the VHS inventors introduced a new and improved format called Super VHS.

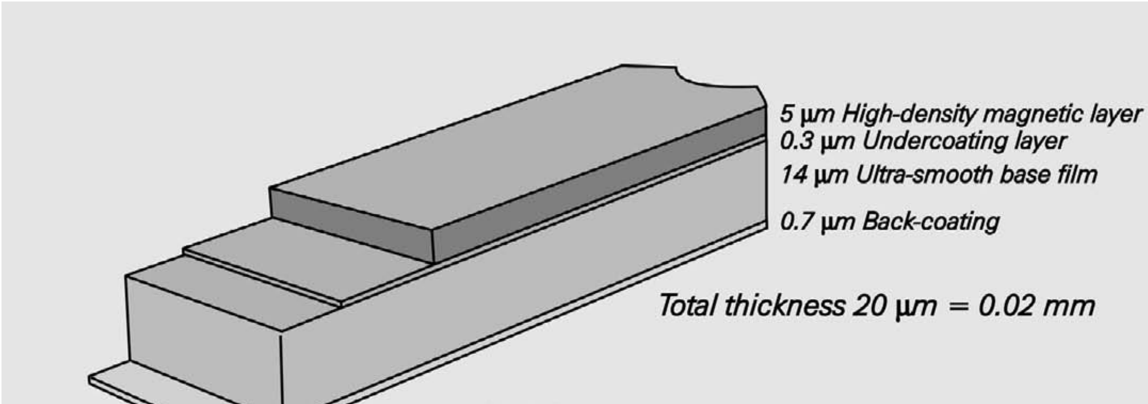
Super VHS, Y/C, and comb filtering

The next major advancement in the development of VHS VCRs came in 1987 with the introduction of the **Super VHS** concept. The Super VHS format improved the luminance and chrominance quality of the recorded video signals, yet preserved downward compatibility with the VHS format. Thus, the same type of video heads rotate with the same speed at the same angle.

S-VHS recorders differ from the VHS basically by their wider bandwidth. This is achieved by separating the color and luminance from the composite video signal with a special comb filter and then modulating the luminance signal with a higher and wider FM band, whose frequency now deviates from 5.4 MHz to 7 MHz. Therefore, a video luminance bandwidth of over 5 MHz can be recorded, giving 400+ TV lines resolution. Video heads of the same physical dimensions are used, but they have better characteristics. Also, although the same sized videotapes are used, the magnetic coating is of a much better quality.



The S-VHS concept



S-VHS tape structure

S-VHS VCRs can record and play back VHS and S-VHS. For a S-VHS recording to be activated a S-VHS tape must be used (the S-VHS recorder recognizes a S-VHS tape by a little slot on the cassette box). A VHS VCR cannot play back S-VHS tapes.

When color and luminance signals are combined in a composite video signal, there is always a visible cross-color and cross-luminance artifact. In order to minimize such deterioration, S-VHS recorders permit direct input and output of the uncombined luminance and chrominance components. This pair is called **Y/C** (Y stands for luminance and C for chrominance) and is found at the back of S-VHS VCRs in the form of miniature DIN (***Deutsche Industrie Normen***) connectors.

If you have a video source that produces Y/C signals (like some multiplexers, VCRs, or framestores), they can be connected to the S-VHS VCR with a special Y/C cable that is composed of two miniature coaxial cables.

Some users erroneously believe that we can only record a high-quality video when a Y/C signal is brought to the S-VHS. This is not true, since the S-VHS was designed primarily for recording composite video signals. For this purpose, a special adaptive comb filter was designed for S-VHS, where the color information is separated from the composite video signal **without losing significant luminance resolution** (as is the case with the low-pass filter in VHS).

An early solution to the Y/C separation problem was to put a low-pass filter on the composite signal and filter out the color signal above about 2.5 MHz in NTSC (above 3 MHz in PAL) to recover the Y signal. The reduced bandwidth of the Y signal dramatically limited the resolution in the picture. A bandpass filter was used to recover the color signal, but it was still contaminated by high-frequency luminance crosstalk and suffered serious cross-color effects.

It is known, however, that the basic composite video signal is periodic in nature as a result of the horizontal and vertical scanning and blanking processes. When such a signal is represented in the frequency domain (a Fourier analysis is applied), it will be represented by **harmonics in precise locations, rather than have uniform spectrum throughout the whole spectrum** of the video signal. This is a very important and fundamental fact in television signal analysis.

By picking the horizontal and vertical scanning rates and the color subcarrier frequency in particular harmonic relationships, the Y/C separation process can be simplified. The color subcarrier frequency in NTSC (and similar logic can be applied to PAL), Fsc, is chosen to be 3.579545 MHz (usually referred to as simply 3.58 MHz). This corresponds to the 455th harmonic of the horizontal scanning frequency, Fh, divided by two (as per the NTSC definitions).

Fh = 15,734.26 Hz

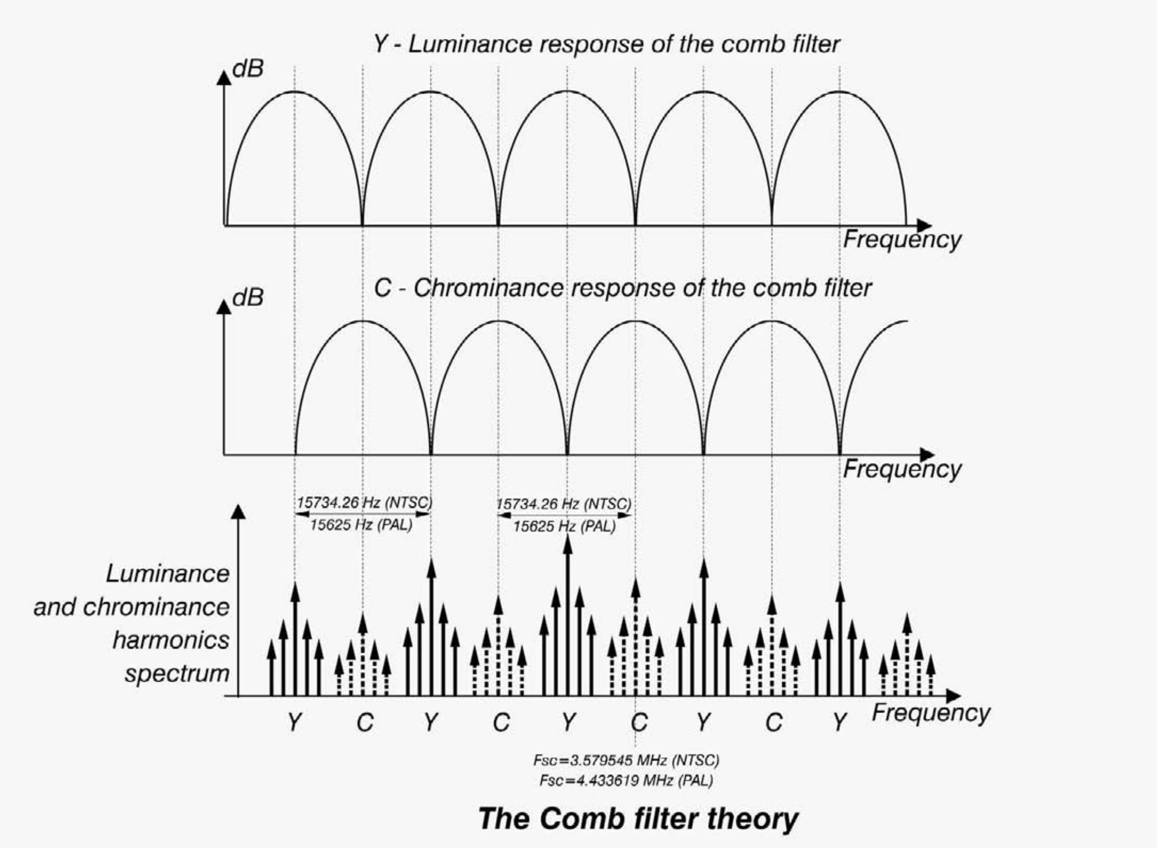
Fsc = 455 × Fh/2 = 3.579545 MHz

Since there are 525 lines in a video frame and a frame consists of two interlaced fields, there are 262.5 lines in a field. Therefore, the vertical field rate is:

Fv = Fh/262.5 = 59.94 Hz

There are also two fields in a frame, so the frame rate is Fv/2 = 29.97 Hz.

Since the video signal is periodic in nature, the spectral distribution of the video frequencies is grouped together in clusters. The Fourier analysis of a static video signal shows that the energy spectrum is concentrated in clusters separated by 15.734 kHz, which is the horizontal scan rate. Each cluster has sidebands with 59.94 and 29.97 Hz spacing. Therefore, the luminance signal does not have a continuous distribution of energy across its bandwidth. Instead, it exists as clusters of energy, each separated by



The Comb filter theory

15.734 kHz. These clusters are not very wide, so **most of the space between them is empty**.

The chrominance signal is also periodic in nature, because it appears on each horizontal scan and is interrupted by the blanking process. Therefore, the **chrominance signal will also cluster** at 15.734 kHz intervals across its bandwidth. By picking the color subcarrier at an odd harmonic (455) of Fh/2, the chroma signal clusters are **centered exactly between the luminance signal clusters**. Therefore, the Y and C signals can occupy the same frequency space by this process of frequency interleaving.

This is the idea behind the comb filters design. A comb filter can be designed to have a frequency response with nulls at periodic frequency intervals. At the center frequency between the nulls, the comb filter passes the signal. If the comb filter is tuned to be periodic at the same 15.734 kHz intervals as the Y/C frequency interleaving, it will **pass the Y signal while rejecting the C** signal or vice versa.

When using Y/C cables between S-VHS components there is minimal cross-luminance and cross-color interference, but for CCTV this is quite impractical since it requires two coaxial cables. The miniature Y/C cable that comes with some S-VHS VCRs is a twin-coaxial cable designed for short runs only, as it has a much higher attenuation than the popular RG-59/U. The main intention of such Y/C connections is for dubbing purposes.

The technology of comb filtering is improving daily. Today the most advanced comb filters are employed not only in S-VHS VCRs but also in high-quality monitors and television sets.

First, it was the ***2D-comb*** filter where not only one line in the video signal but the previous and the next one was used to compare the color content and decide on the optimum filtering (thus, 2D). Further improvement brought the ***3D-comb*** filtering and digital comb filtering, where not only information in one TV field, but the previous and next fields are processed for the color content (thus, 3D). New developments are further improving the resolution and color fidelity.

Of the units you might have, an S-VHS recorder, for example, and a TV monitor, both of them might have comb filters but not necessarily of equal type and quality. It may happen that a better picture quality will be reproduced if a composite video signal is brought from the recorder and the TV is allowed to extract the color information with its own comb filter (if it is of a better design), rather than having Y/C cable connection between the S-VHS VCR and TV monitor.

So, using S-VHS recorders in CCTV with high-resolution color cameras and a single coaxial cable for composite color video signal is still far superior than using VHS VCRs. The quality of the recorded signal is ensured by the high-quality adaptive comb filter built in the S-VHS VCR, and the played back signal will be as good as the monitor can show. If a high-resolution color monitor is used, which would also have its own comb filter, the quality will be much better than using TV monitors designed for commercial use. If we assume that a camera has 470 TV lines of horizontal resolution, the S-VHS VCR has about 400 and the monitor 600 TV lines, the VCR will still be the bottleneck for the played back resolution and the played back signal should have around 400 TV lines (providing, of course, S-VHS tape is used).

Another minor note not found in many technical topics related to S-VHS VCRs is in regards to the LP/SP (long play/standard play) modes. The S-VHS quality is achievable in LP mode as well as in SP

mode. A very minor deterioration of the higher frequencies recorded takes place because of the closer video tracks and slower tape movement, but this is almost undetectable.

Consumer VCRs for CCTV purposes

A very trivial question that I have often been asked by nontechnical people is, Can I connect a CCTV camera to my VCR at home and record and view it on my TV? The answer is yes, although you should be aware of the reduction in recorder quality when compared to dedicated CCTV equipment.

A typical domestic VCR, apart from the RF (antenna) input, also has the audio/video inputs. In most cases, they are in the form of phono sockets (some call them RCA connectors) – one for a basic bandwidth video (this is, as we said earlier, what the CCTV camera gives us) and the other for an audio signal. So, a CCTV camera video signal should be connected directly to the video input of the VCR, with an appropriate adaptor (BNC-RCA). Then, the video output terminal of the VCR (the same type of RCA connector) has to be connected to the video input of the TV receiver. Both the VCR and the TV **have to be switched to A/V channel,** and then the CCTV camera should appear on your TV screen.

If your TV receiver **does not have an A/V input**, however, then the RF output of the VCR should be taken to the RF input (or the antenna input) of the TV set. Understandably, **the TV now has to be tuned to the VCR channel**, which in most cases should be UHF (36–39), as this is a dedicated area for VCRs, but some older models may modulate their signal in the low VHF channels 0, 1, 2, or 3. Also in this case, the VCR has to be set to the A/V channel in order to pass the CCTV camera signal from its video input to the RF output. In both of the above cases, **the VCR is in between the camera**



Walls of VCRs in Sydney's Star City Casino record all cameras in real time mode, fully managed by the matrix switcher.

and the TV. When viewing a live signal or recording, the picture is displayed on the TV, and when playing back a recorded signal, the VCR cuts the incoming live signal and shows the recorded image on the same TV.

When compared to the CCTV dedicated time-lapse VCRs (discussed in the next heading), the disadvantages of the domestic VCR models are manyfold: there is no time and date inserted in the recorded video signal, there are no external alarm trigger inputs, and maximum recording time can be achieved in long play mode, which is not longer than 10 hours for PAL or over 8 hours for NTSC. There are, however, some clear advantages: the price of a normal VCR is very low and affordable, and the images are recorded in full motion – 50 fields per second for PAL and 60 fields per second for NTSC.

Because of the above-mentioned advantages of domestic VCRs, some matrix manufacturers have designed special hardware and software interface devices for their matrix switchers, so as to be able to intelligently control VCRs. This is usually done by intercepting the infrared control section of the VCR, and full control over the recorders is taken from the matrix. In large systems it is almost as expensive, if not more so, to incorporate MUX-es and TL VCRs instead. Because of this reason and because of the requirement for real-time recording all the time, this solution has been especially attractive for large casino installations. With a properly designed and programmed matrix system, it is possible to fully automate and control hundreds and hundreds of VCRs except when tapes need to be changed.

Tape label	Tape length (m)	NTSC time (min)	PAL time (min)
E30	45	22	30
E60	88	44	60
E90	130	65	90
E120	173	86	120
E180	258	129	180
E240	346	173	240
T20	44	20	28
T30	64	30	42
T45	94	45	63
T60	125	60	84
T90	185	90	126
T120	246	120	169
T160	326	160	225

At this point we should also mention that owing to the different recording speeds in the two television standards discussed in this book (PAL and NTSC), we also have different videotape length, and consequently, slightly different recording/playback time. The accompanying table on the previous page should give sufficient information for such discrepancies. Please note that international tape marking for PAL system machines is with “E” and for NTSC machines with “T.”

Time-lapse VCRs (TL VCRs)

Time-lapse VCRs are a special category of video recorders, developed specifically for the security industry.

The main difference between the TL VHS VCR and domestic models is the following:

• TL VCRs can record up to 960 hrs on a single 180-minute tape (PAL) or 120-minute (NTSC). Other time-lapse modes between 3 and 960 are available: 12, 24, 48, 72, 96, 120, 168, 240, 480, and 720 hrs. This is achieved by the time-lapse stepper motor that moves the tape in discrete steps, while the video drum rotates constantly. Usually up to the 12-hr mode, the tape moves with continuous speed, after which, starting from 24, it moves in discrete steps. The time-lapsed between subsequent shots increases as the mode increases. Typical times are shown in the table on the next page.

The modes mentioned refer to a 180-minute or 120-minute tape, depending on the television system in question. If a 240-minute tape is used instead, the corresponding TL mode increases by 1/3; that is, 24 hrs becomes 32, 72 becomes 96, and so on. The same logic applies when a 300-minute tape is used, where TL modes are increased by 2/3; that is, 24 hrs becomes 40, 72 becomes 120, and so on. Please refer to the table on next page for more details.

When a TL VCR is recording in TL mode, no real-time movement is recorded because there are not 50 fields (60 for NTSC) recorded each second. The playback looks like a video playback in Pause mode, advancing at short but regular intervals, as per the table. TL VCRs can record and play back in any mode, regardless of which it was recorded in. In pause mode, still frames (fields) have exceptionally good quality. When unstable, a special still lock adjustment potentiometer, not available on commercial VCRs, can stabilize the picture to a perfectly still frame. This is of great importance for verification purposes.

• TL VCRs have no tuners; that is, normal RF reception is not possible.

• TL VCRs can be triggered by an external alarm, which will cause the unit to switch instantly from TL mode into real time for a preset duration (15 s, 30 s, 1 min, 3 min) or until the alarm is cleared, after which it goes back into TL mode. Usually, voltage free N/O (normally open) contacts are expected as the alarm input. This is a very powerful function of TL VCRs. When an alarm is recorded, most TL VCRs index the tape so that a quick search of the alarmed area is possible. Some makes offer search by time, date, and hour, and others offer alarm scan as well, which can be very convenient when more than one alarm has to be reviewed every day.

• TL VCRs pass the incoming alarms out in a form of alarm voltage output that can be used to trigger an additional device such as a buzzer, strobe light, or similar device.

• TL VCRs can be programmed to recycle-record, which is very useful when the tape duration expires earlier than expected and there is no operator to replace it.

• The MTBF of a video head used in TL VCRs is usually about 10,000 hrs, which is equivalent to about one year of constant play/record operation. After this, head replacement is recommended. All TL VCRs have some form of indication of the head's hourly usage. This is displayed either on a mercury-based indicator or electronically when the setup is performed.

• Some TL VCRs can be programmed to record only one shot with each alarm input. Using this type of recording we can fit more than 960 hrs on a single tape.

NTSC			PAL		
Tape hours	Fields per second	Refresh rate (sec)	Tape hours	Fields per second	Refresh rate (sec)
002	60.0	0.0167	003	50.0	0.02
012	10.0	0.1	012	12.5	0.08
018	6.66	0.15	018	8.33	0.12
024	5.0	0.2	024	6.25	0.16
048	2.5	0.4	048	3.125	0.32
072	1.7	0.58	072	2.083	0.48
120	1.0	1.0	120	1.25	0.8
168	0.7	1.403	168	0.89	1.12
240	0.5	2.0	240	0.625	1.6
360	0.33	3.0	360	0.416	2.4
480	0.25	4.0	480	0.3125	3.2
600	0.20	5.0	600	0.25	4.0
720	0.16	6.25	720	0.208	4.8
960	0.12	8.0	960	0.156	6.4

TL VCRs also have, as the standard VCRs, timer settings, which means they can be programmed to record only at certain times and on certain days.

TL VCRs are important devices in CCTV, even though they are the weakest link in the resolution chain. Apart from their use in multiplexed recording, one of the most important features is their ability to switch to real-time recording when an external alarm is received. Most of the models available on the market can be switched from stop mode to real-time recording, but it is more advantageous when the same alarm switches the VCR to real time while it is already recording in time-lapse mode. The reason is very simple: VCRs, being electromechanical devices, have inertia. This means a few parts of a second (and sometimes even more than a second) might be lost until the video head starts spinning and the tape is wound around the drum. If a TL VCR is already recording in time-lapse mode, it takes only a few milliseconds to change to real-time recording because the tape is in place and the video heads are already spinning. If tape wastage is of concern (due to the low hours of time-lapse recording that are not necessary), the longest time-lapse mode can be selected.



Photo courtesy of Gyyr (an Odetics company)

A time-lapse recorder

Some TL VCRs, or even domestic models referred to as Quick Start, have the tape already wound around the heads and are ready to record even in stop mode. They have a better response than other VCRs, when the record button is pressed. Be aware that on most domestic models there is a certain time delay during which the machine will be in standby mode, after which the tape unwinds. This could be only a minute or two, or sometimes up to ten.

Many installers have modified domestic model VCRs for alarm recording, which is reasonably easy to do. The record button contacts are paralleled and connected to a relay that is controlled by an external alarm. In such cases, the VCR's warranty will be void. Another important detail is that there is no time and date stamping when an alarm triggers such a VCR.

VHS VCRs' horizontal resolution limitations (vertical is still defined by the TV system in use) are, as mentioned earlier, 240 TV lines for a color signal. Because CCTV still uses a lot of B/W cameras, most TL VCRs have a switch for selecting between B/W and color. When set to B/W, the video signal bypasses the low-pass filtering used for extracting the color information from a color signal, thus allowing for an improved horizontal resolution for a B/W signal, in excess of 300 TV lines (which also depends very much on the tape quality and how clean the heads are).

If we want an even better recording quality than what the VHS format offers, we can use time-lapse Super VHS models. They offer the same flexibility and programmability as the VHS TL VCRs, only they are of better picture quality and more expensive.



A S-VHS time-lapse VCR

Whichever type of video recorder you use (and this also refers to domestic VCRs), the video signal resolution should not be taken for granted. It could be much worse than in theory, if any of the following requirements are not met:

• For starters, connect a good video signal to the VCR input. This is especially important for the horizontal sync pulses of the signal since they are reproduced from the tape as part of the video signal. If the camera is very distant, with distorted syncs and color bursts (voltage drop and high-frequency losses), the video playback will be very unstable, with picture breaking across the top and unstable colors. Because the tape and the heads limit the resolution even further, the quality of the sync pulses is also affected. How these distortions are reproduced on a monitor screen depends very much on the monitor's sync-handling capability, but if the sync pulses (and video information) are recorded poorly, there is little else that can be done by the monitor.

• Always use good-quality tapes. The uniformity of the magnetic coating and the film base quality is very important. Good tapes not only improve the recording quality, but also prolong the life of the video heads and VCR mechanics in general. Bad tapes (or imitations of known brands) have a nonuniform magnetic layer, which quite often peels off, and microscopic particles accumulate on the video heads, causing more damage than saving dollars.

• Video heads need regular cleaning, but it should be done only with approved cleaning kits. The best thing to do is to consult your local video shop or service. They have valuable practical experience in VCRs which you could apply to CCTV. If you do not clean your VCR for a long period, snowy playback is what you will see. To confirm that it is a dirty head and not a bad tape or signal (which may look similar), take a tape of a known brand and



Typical connections at the back of a TL VCR

make sure it has been properly recorded, then play it back. If the snowy picture is still there, the video heads need cleaning. Do not confuse the snow produced by dirty heads with the need for tracking adjustment. The difference is in the amount of snow. The tracking usually needs adjustment if the bottom of the monitor shows picture breaking.

The table at the beginnig of this heading gives the number of fields recorded every second with different TL settings, in both of the major TV systems, NTSC and PAL. The refresh rate represents the time gap between the subsequent fields.



OptiVision
DIGITAL
INTEGRA
Dallmeier
Net DVR
NICE
Velbon CX 300

9. Digital video

All of the discussions in this book so far have involved PAL and NTSC television standards, which refer to analog video signals. The majority of CCTV systems today would still have analog cameras, even though an increased number of manufacturers offer digital video (IP) cameras designed to "stream" video over network.

The very few components in CCTV that, only a half a dozen years ago, used digital video were the framestores, quad compressors, multiplexers, and the internal circuits of the digital signal processing (DSP) cameras. Today, we can freely say that the majority of new installations, though still working with analog cameras, use digital video recorders for monitoring and long-term storage. Camera quality is an important starting point in the CCTV system video chain, but the quality of the recorded images and its intelligent processing have become equally important.

In the interval since the first edition of this book (1996), there have been revolutionary developments in TV, multimedia, video, photography, and CCTV. The majority of these developments are based on digital technology. One of the locomotives of the real new boom in CCTV has been the switch to digital video processing, transmission, and recording. This development gathered a real momentum in the last few years – hence the reason for a complete new edition of this book with extended discussions on digital, video compression, networking, and IP technology.

Only a few years ago, the price of high-speed digital electronics capable of live video processing was unaffordable and uneconomical. Today, however, with the ever increasing performance and speed of memory chips, processors, and hard disks, as well as their decrease in price, digital video signal processing in real time is not only possible and more affordable, but it has become the only way to process a large number of high-quality video signals.

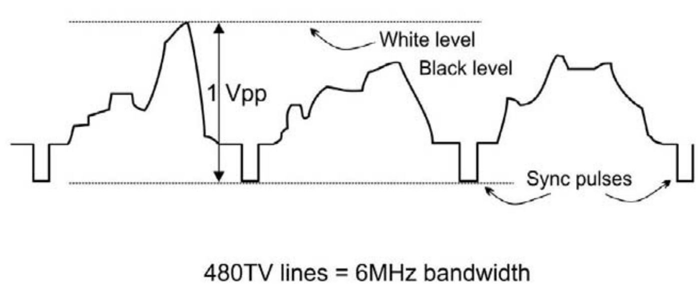
Digital video was first introduced in the broadcasting industry in the early 1990s. As with any new technology it was initially very expensive and used rarely. Today digital video is the new standard, replacing the nearly half a century old analog video. It comes basically in two flavors – ***Standard Definition (SDTV)*** with the aspect ratio of 4:3 and the quality as we know it, and ***High Definition (HDTV)*** with the aspect ratio of 16:9 and around 5 times the number of pixels of SDTV. Many countries around the world are already broadcasting digital video, usually in both formats (SDTV and HDTV). Not surprisingly, the HDTV is going to be the preferred choice of the consumer market, owing to its much higher resolution and the theatrical experience one has watching movies, but since in the majority of CCTV today we use the standard definition resolution in this chapter, we will cover all the key features that refer to standard resolution video, with a 4:3 aspect ratio.

Digital video recorders (DVRs) and IP cameras have now become the main reason for the new CCTV growth, a source of higher revenue and an inspiration for new and intelligent system design solutions that have blurred the line between computers, IT technology, networking, and CCTV.

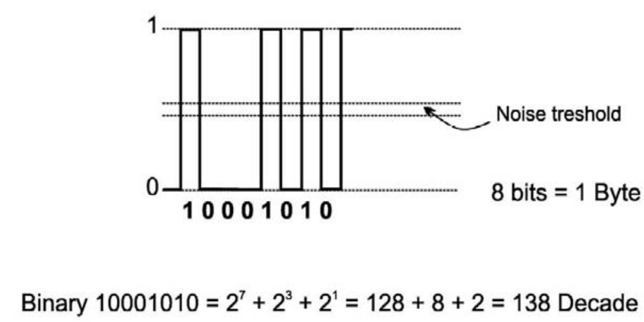
Why digital video?

Analog signals are defined as signals that can have any value in a predefined range. Such analog signals could be audio, but also video. As we know, the predefined range for video signal is anything from 0 volts (corresponding to black) to 0.7 volts (corresponding to white).

As mentioned earlier, most of the CCTV cameras today produce analog signals. But the main problem with analog signals is that noise is easily induced onto them, and, as we know, in real life noise cannot be avoided. It is just accumulated at every stage of the signal path. Starting from the thermal noise at the camera imaging chip, the camera electronics itself, it adds in the transmission media (cables) and at the receiving end (recorders, monitors, etc.). The longer this path is the more noise it will get induced. This is where digital signals can make a big difference. So, **one of the most important differences between an analog and a digital signal (apart from the form itself) is the immunity to noise**. A digital signal is also affected by noise, as is the analog signal, but digital signals can only have two values: zero or one. Noise will only affect the signal when its value reaches levels that may interfere with the digital circuit margins that decide whether a signal is zero or one. This means that digital signals allow noise accumulation to an extent unimaginable with analog video signals, which is why we say **digital signals are virtually immune to noise**. As a result, this means longer distances, high immunity to external EMIs, and no signal degradation, (i.e., better picture quality).



Analog video signal representation



Digital video signal representation

The other important advantage of digital video signals is the possibility for digital processing and storage. This includes image enhancement, compression, transmission, various corrections, and storage. Also an important feature is that **there is no difference in image quality between the copies and the original**. Whether we make one, two, or ten copies of the image captured in a digital format, the quality is exactly the same as the original no matter what generation copy it is. And last, but not the least important feature with video captured in digital format is the **possibility of checking the originality of a copy**. This feature is very often referred to as "***water-marking***," and it enables the protection of digital signals against deliberate tampering, a very important aspect for CCTV security applications.

There are two main groups of compressions used in CCTV: ***video*** and ***image compressions***.

Digital video recorders (DVRs)

Today it seems that recording CCTV video on VCR tapes is nearly over. Five years ago, during completion of the previous edition of this book, VCRs were still around in big numbers, and DVRs were only starting to appear. Today this ratio is reversed.

So what are the real benefits of using DVRs in CCTV, as opposed to VCRs?

First, with the VCR's analog method there is no direct and quick access to the desired camera, except when using a reasonably quick Alarm Search mode (available on most TL VCRs). In VCRs the information is stored in an analog format and cannot be further processed. The VCR recorded video quality is always lower than the actual original source.

Initially, in CCTV, attempts were made to implement digital video recording on a digital audio tape (DAT) format. Though digital, such recorded material still required a sequential search mode, which is not as efficient as the random access used in a hard disk. Hard disks have a much higher through-output than other digital storage media and higher capacity; better than S-VHS quality images are achievable with appropriate video compressions. What was a problem only a few years ago – the length of recording – these days is no longer such. Hard disks with capacities of 300 GB are readily available, and DVRs with internal capacities of 1200 GB (1.2 TB) are not a rarity. Multi-week recording of a number of cameras is no longer a problem. Hard disk drives (HDD) now have fast access time, and by using good compression it is possible to record and play back multiple images from one – in real time (meaning "***live***" video rate). The hard disk prices are falling daily and it is interesting to note that at the time of writing the previous edition of this book, a single 3.5 inch HDD with the capacity of around 30 GB was becoming available. For the same price, today in 2005, we have a nearly tenfold increase in capacity, with 300 GB and 400 GB already been advertised. Because of the importance of the hard drives, the need arose for a complete new chapter discussing all the important aspects of it.

How many days or weeks of video recording can be stored on a 300 GB, for example, depends first on the type of compression and the quality of images elected for such compression. Also, an important factor would be if the recording were made permanent or if it was based on video motion detection. The latter one has become very popular in CCTV as it extends the recording capacity at least two or threefold. Certainly, extending the hard drive storage is also possible, but providing redundancy (safety) as well might be an important request by a customer.

Because there are so many variables, it is not easy to give a uniform answer. I am also aware that the first question many customers ask is how many days of recording they will get; therefore, in order to help you out, I have put two different spreadsheets on our web site (***www.cctvlabs.com***) which you can download and use. The first one refers to multiplexed image compressions, and the other to video compressions, which are all explained further in this chapter.

All of the above leads us to various considerations we have to have in mind when selecting digital compression, storage media, and data transfer rate. This is why we have to understand the theory of digital video and image representation with various compression techniques. The following few headings will try to explain some of the basics.

The various standards

A few international bodies engage in various standards for digitized video. The most well known is the ***International Telecommunication Union*** (**ITU**), which is the United Nations specialized agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating, and tariff questions and for issuing recommendations on them with a view to standardizing telecommunications on a worldwide basis. The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce recommendations on these topics. The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1. In some areas of information technology that fall within ITU-T's review, the necessary standards are prepared on a collaborative basis with ISO and IEC.

ISO (the ***International Organization for Standardization***) and **IEC** (the ***International Electrotechnical Commission***) form the specialized system for worldwide standardization. National bodies that are members of ISO and IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and nongovernmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC1. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75% of the national bodies casting a vote.

Some recommendations, such as the latest H.264, are prepared jointly by ITU-T SG16 Q.6, also known as VCEG (***Video Coding Experts Group***), and by ISO/IEC JTC1/SC29/WG11, also known as MPEG (*Moving Picture Experts Group*). VCEG was formed in 1997 to maintain prior ITU-T video coding standards and to develop new video coding standard(s) appropriate for a wide range of conversational and nonconversational services. MPEG was formed in 1988 to establish standards for coding moving pictures and associated audio for various applications such as digital storage media, distribution, and communication.

It should also be made clear that even though in CCTV we use video signal and we will talk about video compression, we also make use of still image compressions. In order to make a clear distinction between these two, we should refer to them as ***video compression*** and ***image compression***.

www.itu.int

www.mpeg.org

Video compressions use three dimensions when compressing: horizontal and vertical picture dimensions, as well as time. As a result, such compressions are often referred to as ***temporal compressions***. Typical representatives of temporal (video) compressions are MPEG-1, MPEG-2, MPEG-4, H.263, and H.264.

Image compressions use only two dimensions: the horizontal and vertical dimension of the image. Typical ***image compressions*** representatives are JPEG and Wavelet (JPEG-2000).

The difficult challenge we face in CCTV is deciding which compression is best for a particular product or project. **There is no simple or single answer.** Often it depends on how much we understand about the differences between compressions, but more importantly on what is the intended usage. If a digital CCTV system is designed to protect a cash teller in a bank, or a card dealer in a casino, a high image rate would be preferred. Often live rates should be used (25 for PAL or 30 for NTSC), although in some instances 10 images/second might be sufficient. A lower rate than this is possible but might not be practical in such applications. Tests are often the best indicator.

Another example would be where normal human activity is recorded, like people walking in and out of a foyer of a building. There is no need for a high rate here as it only adds gigabytes to the storage which somebody has to eventually be able to go through and analyze. And this takes a lot of time, reducing the efficiency of the system. Human activity can successfully be captured even at 2 images/second (although the more the better), providing the image quality is high and the compression is low. How much detail can be seen and recognized depends on the lens angles of coverage, but if a camera produces a signal where a person's face can be identified when viewing in live mode, a couple of images per second of the same should be sufficient to make identification after the recording successful.

The other important recording technique we use in CCTV is the multiplexed recording. With digital CCTV, we tend to mimic what was done in the days of multiplexed recording when we used multiplexers and VCRs. So a typical CCTV digital video recorder (DVR) in actual fact is a multiplexer and digital recorder in one. In such products, image compression (as opposed to video compression) would be more convenient as it compresses TV frames or fields treating them as still images, without regard for which camera comes before or after the compressed one. Some would argue that the disadvantages of image compressions used in multiplexing DVRs are that they end up as relatively large image files (typically, 30 kB – 60 kB per TV field, for a good image quality), but the pros are that each such image is an independent entity and can be reconstructed on its own without the need for other images before or after it to be available. For some legal cases this might be the preferred compression because of such independence. This is not to say that video compressions cannot stand the court of law, but it is only the interpretation of the argument that video compressions uses reconstruction based on past and future reference images. With image compressions it is possible to have image rates much lower than the live rate of 25 frames/second (29.97 for NTSC), making the most of the available hard drive storage space. If we add to this the motion detection capability, which most of the multiplexed DVRs use, we get a superior successor to the MUX+VCR combination. This is why it is possible to have multiple cameras recorded on one DVR, each with at least a couple of images per second recording rate, and achieve storage capacities of several days, weeks, and maybe months. This was unthinkable only 5 to 10 years ago.

In recorders where we want to achieve the highest possible video quality or highest possible recording or transmission rate, temporal compression is better suited as it makes use of the redundancy of a video signal over time. It does require, however, a continuous signal of the same camera for maximum efficiency. The other advantage of temporal (video) compression is that audio is almost always part of such a scheme. Temporal compressions makes better compression of the video sequence as it uses motion prediction (not to be confused with motion detection) so that object motion looks smoother when playing back. Because of this fact, video compressions are not used to multiplex cameras into one recording system. Rather, if a DVR that uses temporal compression has multiple camera inputs, they are usually independent steamings recorded on hard drives.

Another important feature associated with temporal compression is the time delay (latency) which happens on video compressions such as MPEG-1 and MPEG-2. This is a result of how the video compression is designed to work, where video signal redundancy is reduced by comparing past and future reference points, a technique that requires some buffering (i.e., produces delays in encoding and decoding). More susceptible to this effect is MPEG-2, where high video quality is achieved with higher bit rates, typically over 4 Mb/s, and this may produce a latency from around half a second up to a second. This delay is irrelevant in broadcast television or when playing back a DVD movie for example, but it becomes an issue when trying to control a PTZ camera whose signal has been encoded for transmission over LAN. It is possible, however, by combining a lower streaming rate and lower ***group of pictures*** (GOP) size to reduce the delay to acceptable 200 ms or less, with unnoticeable video quality deterioration.

The temporal (video) compressions that use lower bit rates and are designed for video conferencing (thus a need for bidirectional video streaming), such as H.263 and MPEG-4, have much lower lag, though lower picture quality too.

Video and image compressions have evolved considerably in the last 10 years. Although in the majority of the



The same photo with 50×50, 100×100 and 200×200 pixels

broadcast and DVD industry, MPEG-2 is the dominant one, it is not excluded that a new and more efficient compression will become more popular. At the time of writing this book, the latest and most promising video compression seems to be H.264 (building on MPEG-4 v.10, and also known as ***advanced video codec* – AVC**), and the latest and most promising image compression seems to be JPEG-2000 (using the Wavelet intelligence). We will see what the future will bring.

So, let us now list all of the compressions that we have or might use in CCTV; we will cover them in more details later in this chapter.

- JPEG and Motion-JPEG (still image compression)
- JPEG-2000 / Wavelet and Motion JPEG-2000 (still compression encoding)
- MPEG-1 (video compression, uses data bit streaming between 1 ~ 3 Mb/s)
- MPEG-2 (video compression, uses data bit streaming between 1 ~ 30 Mb/s)
- MPEG-4 (video compression, uses even lower bit rates, from 9.6 kb/s ~ 1.5 Mb/s)
- MPEG-7 (new concept, offering smart object searching features)
- MPEG-21 (very new, promising larger scale integration of smartness of all MPEGs)
- H.261 (one of the first and oldest video compressions, designed for video conferencing, uses multiples of 64 kb/s, typical for ISDN)
- H.263 (improved H.261, works with even lower bit rates)
- H.264 / AVC (new and advanced video compression for generic audiovisual services)
- Others (proprietary and hybrid compressions)

There are also hybrid compressions, which combine the features of the two above groups, such as the ***Delta Wavelet*** compression, the ***Multi-Layer JPEG***, and some other proprietary formats.

It is important to acknowledge that all compressions defined by the standards can be made in the hardware, by dedicated processing chips, as opposed to the proprietary ones which, although they may offer some advantages, are done in the software by the general purpose operating system and the processor in the DVR. Thus, the continuity and consistency of such compression will very much depend on how fast and how busy the main processor with other activities is.

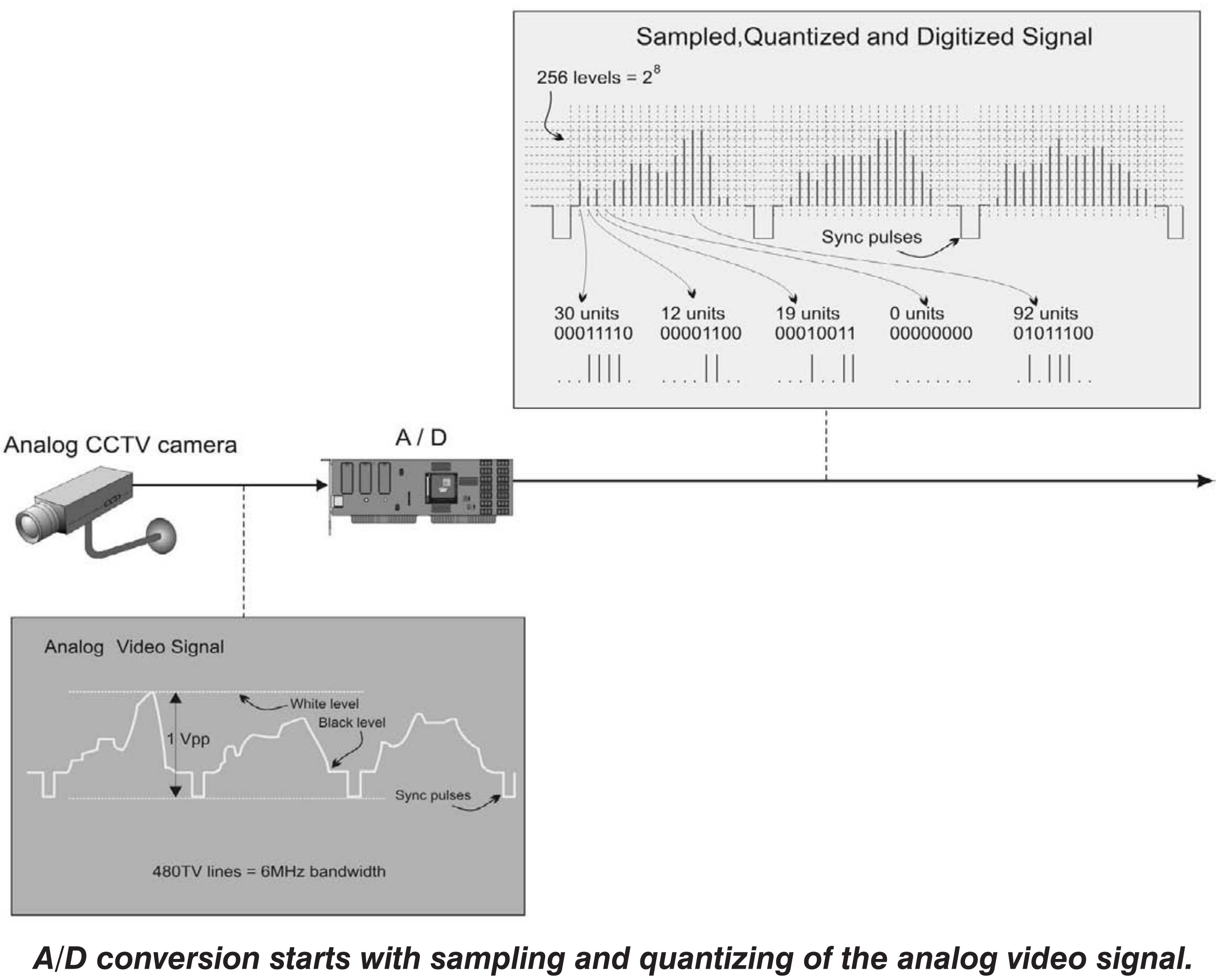
The advantages of the hardware compression chips are obvious: their compression speed is independent (i.e., constant) of the other activities taken by the main processor (web serving, backing up, remote transmission, etc.).

Admittedly, software compression can easily be modified, and new features can be added, as it only depends on the easily updated software code.

ITU-601: Merging the NTSC and PAL

Prior to any digital processing, the first stage is ***analog to digital conversion*** (A/D). Such a circuit could exist inside an IP camera, or a DVR. This is a stage where the analog signal is sampled and quantized (broken into discrete values) in order to be converted to digital format. The sampling rate and levels of quantization depend on the quality and speed of the electronics, and they define the resolution (image quality) and the speed of the digital frame grabbing device. It is important to understand here that, although theoretically a variety of A/D quality conversions might be used in terms of sampling rates and quantizing levels, a television digitization standard has been established and the majority of CCTV products use it.

The ***ITU-R BT.601*** recommendation specifies the digitization of analog video signal comprised of luminance Y, red color-difference component, and blue color-difference component with a ***sampling base frequency*** of 3.375 MHz, common for both PAL and NTSC. The luminance Y is sampled with four times of this "base" frequency (i.e., 3.375 × 4 = 13.5 MHz), and the color difference components with two times the base frequency (i.e., 6.75 MHz). Hence this sampling arrangement is also known as 4:2:2 sampling. Other sampling strategies are also possible, such as 4:1:1 and 4:4:4, but the 4:2:2 is the most common in CCTV.



A/D conversion starts with sampling and quantizing of the analog video signal.

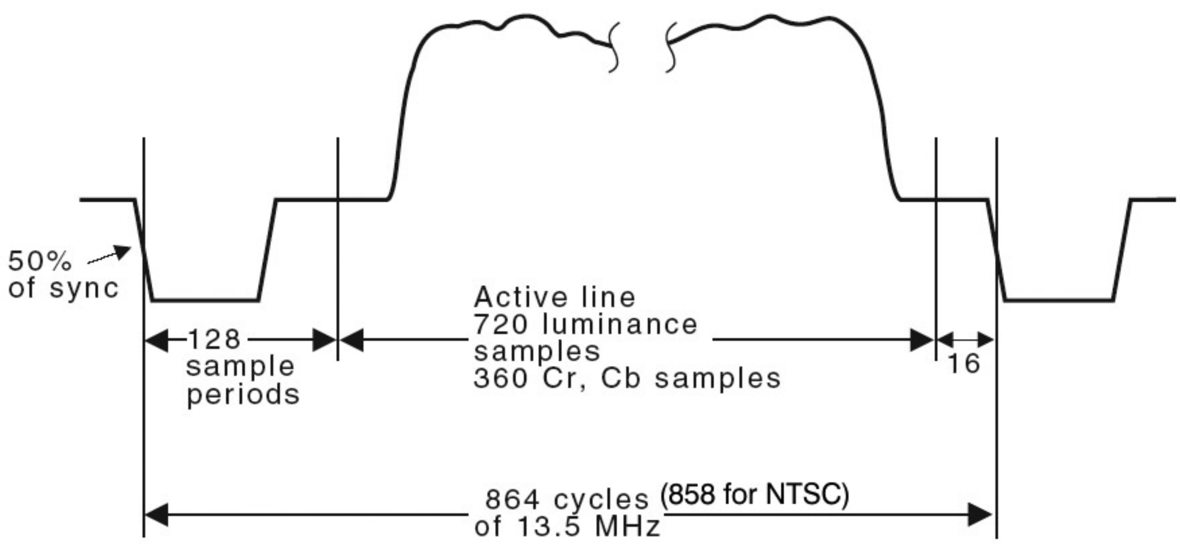
If we refresh our memory about PAL scanning lines and number of frames we get each second, we can calculate that there are 625 × 25 frames = 15,625 lines each second. If we divide the 13.5 MHz sampling rate (which is 13,500,000 times each second) with 15,625 Hz we get 864 samples per line. This is the quality of the sampling in PAL when using the ITU-601 recommendation of 13.5 MHz. Since PAL line duration is 64 μs (see the diagram), the sampling rate of 864 "slices" this time width in pretty fine slices. It should be noted that this "slicing" includes the sync pulses as well.

The same type of calculation for NTSC, using 525 scanning lines at 59.94 Hz field rate (the accurate field frequency is 59.94, not 60) obtains 525 × 29.97 Hz = 15,734.25 lines each second. Dividing 13.5 MHz by 15,734.25 Hz gives 858 samples per line, including, again, the sync pulses.

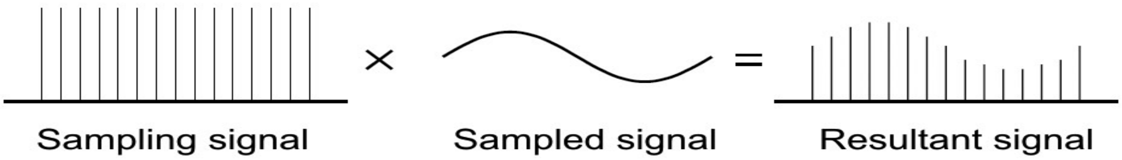
So, just to recap, **using the ITU-601 recommendation in PAL luminance sampling, we get 864 samples/line, and in NTSC we get 858 samples/line. In both cases a sampling frequency of 13.5 MHz is used**.

From the above, a very important fact about the ITU-R BT.601 can be concluded: **the ITU-601 is the first international recommendation that tries to merge the two incompatible analog composite television standards (NTSC with 525/59.94 and PAL with 625/50) to a common component digital sampling concept. The major achievement of Rec 601 is choosing a set of sampling frequencies of 13.5 MHz which is common to both standards.**

Out of the 864 samples for PAL and 858 for NTSC, **the active line in both cases is given to have 720 samples**. This is the maximum horizontal resolution a digitized signal using ITU-601 sampling recommendation can have. The term ***resolution*** should be used loosely here because it has a slightly different meaning than the analog video signal resolution expressed in TVL. We shall explain this in more detail further in the text.



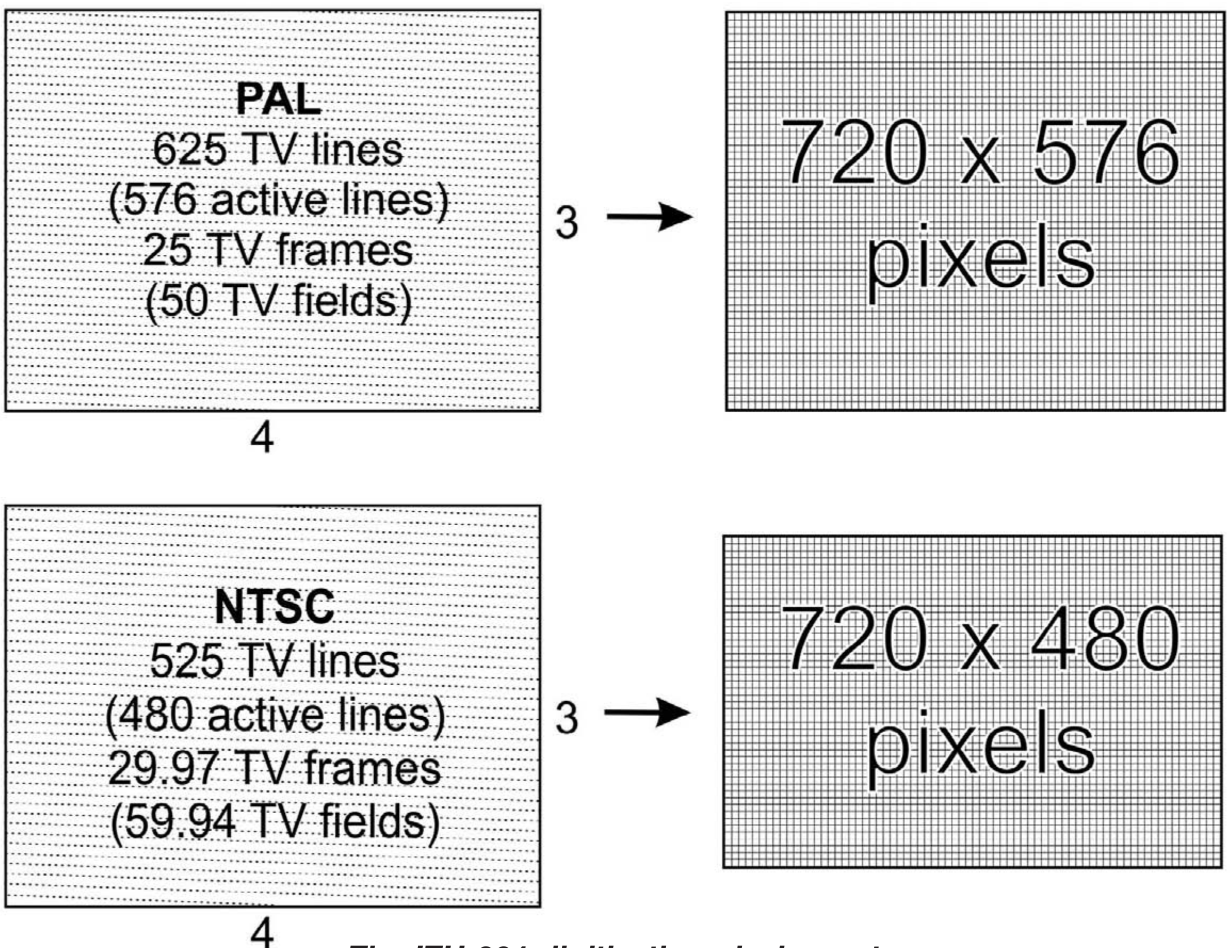
The sampling rate as recommended by ITU-601



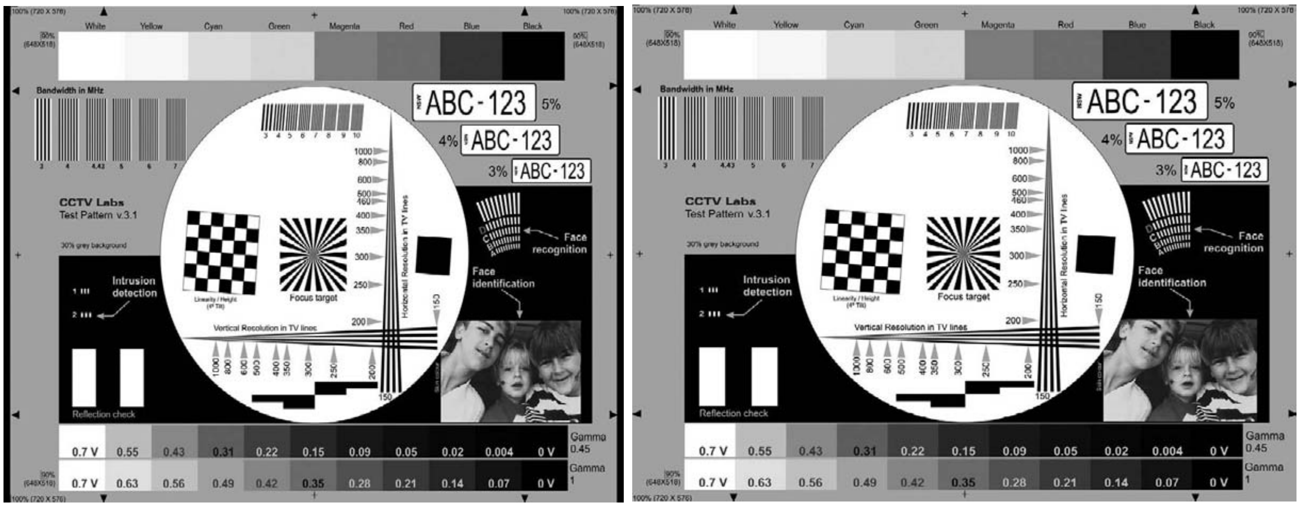
Some of you may ask, "Why 720, and not less or more than that?" This is because 720 is a number, divisible by 8 (i.e., 2^3), which is very useful for most of the video compressions using ***discrete cosine transformation*** (such as JPG, MPEG and H series) where video images are subdivided in blocks of 8 × 8 pixels. Often, you will find that some digital processing equipment will narrow the active video signal by 8 samples to the left and 8 to the right of the main video signal contents of 720 samples, making an active line consist of 704 pixels instead of 720. This is to allow for the various camera signal fluctuations.

The vertical sampling recommendation by ITU-601 is equal to the number of active lines, which is 288 per TV field (or 576 for a full TV frame) in PAL and 240 per TV field (or 480 for a full TV frame) in NTSC.

Therefore, **the digitized TV frame according to the ITU-601 recommendation is 720 × 576 for PAL and 720 × 480 for NTSC.**



The ITU-601 digitization pixel count



An example of a test chart as sampled by the ITU-601 recommendations (note the horizontally "squashed" appearance) in PAL on the left, and how it is reproduced at the analog video output on the right

This fact also indicates that the ITU-601 considers the interlaced scanning effect and in many digital recorders a choice can be made if the recording is to be in field or frame mode.

An observant reader would notice in these numbers something that makes digital CCTV sometimes confusing, and because of that it is worth clarifying it now. This is the aspect ratio of the standard definition TV and the aspect ratio of the images produced when sampled with ITU-601 recommendation. As we all know, all TVs and monitors in CCTV use an aspect ratio of 4:3 = 1.33, and yet the aspect ratio of 720:576 = 1.25 for PAL and 720:480 = 1.5 for NTSC. This introduces so-called "***non-square***" pixels in both of these standards. The PAL gets "horizontally squashed" pixels, which need to be stretched out before reproduction onto a 4:3 aspect monitor, while the NTSC gets "vertically squashed" pixels, which need to be expanded vertically before displaying it onto a monitor. This expansion/stretching is done in the last stage of the decoding before it gets displayed. It may seem as if this is an unnecessary stage in digital, but in actual fact it makes the decoding chips cheaper and more universal, since they are used in both PAL and NTSC.

The resolution of ITU-601 digitized video

Based on the Nyquist theory, an analog and continuous signal can be reproduced from its discrete samples if the sampling frequency is at least twice the highest bandwidth frequency. Higher frequencies than the highest bandwidth are not wanted and in actual fact if they do exist they cause aliasing (like the well-known Moiré patterning). In order for the aliasing to be minimized, the sampled signal has to pass through a low-pass filter where frequencies higher than the upper frequency (equal to half the sampling frequency) are being deliberately eliminated. An ideal brickwall low-pass filter doesn't exist in practice, so the actual filter cutoff frequency is slightly lower than what the theory needs it to be. This fact has a direct bearing on the frequency response and the number of horizontal picture elements (pixels) that a digitized system can handle.

In ideal conditions, if no additional filtering was done, given the Nyquist frequency of 6.75 MHz (i.e., a sampling rate 13.5 MHz), the 720 pixels per active line would be equivalent to a horizontal resolution of 3/4 × 720 = 540 TVL, as defined by the analog TV.

The ITU-601 recommendation, however, specifies an anti-aliasing and reconstruction filter cutoff of 5.75 MHz, which reduces the luminance analog horizontal resolution to 449 TVL in PAL and 455 TVL in NTSC.

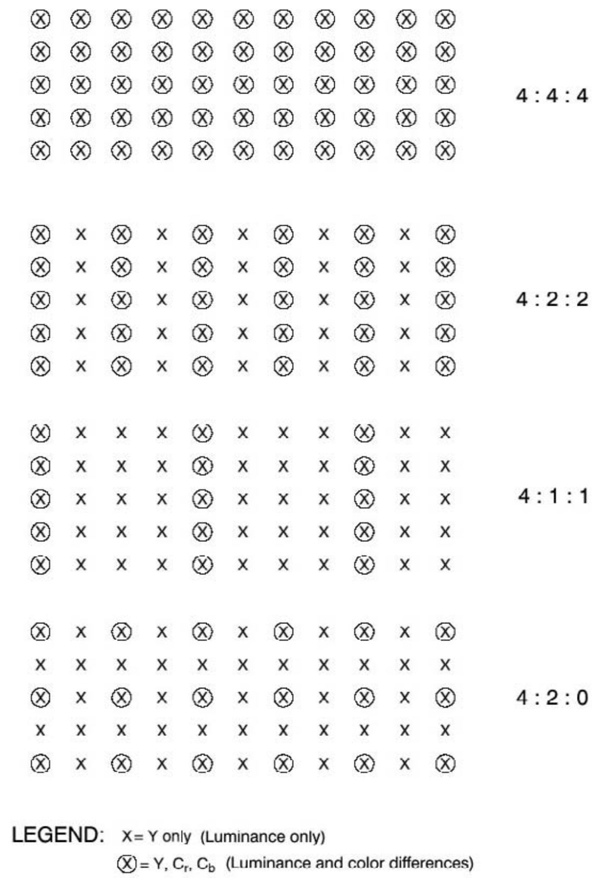
Further reduction of the resolution is introduced by the video compression itself, so in practice it is fair to say that **no video signal in digitized CCTV can have any higher horizontal resolution than around 450 TVL**. It now becomes very clear that choosing a video compression that has as few losses as possible is of paramount importance. This desire contradicts the requirement for long recording storage. We will discuss the various video compressions further in this chapter, but **it is important to highlight again that the above resolution limit applies to the digitized video signal, before it undergoes the compression.**

The human eye is less sensitive to color resolution, and because of this in CCTV we do accept 4:2:2 sampling strategy as good enough, where the chrominance signals are subsampled by a factor of two, at 6.75 MHz (only half the luminance sampling of 13.5 MHz). This results in 432 total pixels for PAL and 429 pixels for the NTSC scanning standard (includes the sync pulses period). So, the digital active



The difference between full frame 720 x 576 pixels image (above) and the same in CIF size (360 x 288) sometimes can make a difference between recognizing a license plate and not recognizing it (for example, the car on the right).

line accommodates the 360 red color-difference and 360 blue color-difference component in both standards. Under ideal conditions, given the Nyquist frequency of 3.375 MHz, 360 pixels per active line is equivalent to 3/4 × 360 = 270 TVL. Rec 601 specifies an anti-aliasing and reconstruction filter cutoff of 2.75 MHz, resulting in a color differences signal analog horizontal resolution on the order of 215 TVL in PAL and 218 TVL in NTSC.



The ITU-601 recommends a variety of sampling strategies, of which in CCTV the 4:2:2 is widely accepted.

All of the above, and especially the facts about the digitized luminance, represents a very important conclusion when are discussing resolution in digitized video. It should be noted that this is the ITU-601 digitization recommendation, and as we said earlier, it is in use in the majority of digitization products in the CCTV. **There is no advantage of using cameras with much higher resolution than 450 TVL when the same is to be recorded on ITU-601 compliant recorders.** This is the same argument as when we had high-resolution cameras (460 TVL for example) being recorded on VHS VCRs (which are limited to 240 TVL by the low-pass filter design). The difference here is not so dramatic, as some CCTV manufacturers lately have come up with color cameras offering 520 TVL, for example. Practically, this means **you cannot see any difference between a 460 TVL or 480 TVL or even 520 TVL camera, when these are to be recorded even on the best quality ITU-601 compliant DVR. More attention should be directed to choosing a camera with a better signal/noise ratio, less smear or better dynamic range than to slight differences in horizontal resolution that nobody can see.** If a system is designed and used for just live monitoring, on high-quality CCTV monitors with better than 500 TVL resolution, such a small difference in resolution might be advantageous, but unless Y/C connection is made to the monitors instead of composite video (and this is really very rare in CCTV), not much difference can be seen even then.

No one can predict what the future will bring, and I am confident that sooner or later we will have some version of high-definition CCTV cameras, which will then be accompanied with the appropriate high-definition digitization recommendation. But, until then, we should all be aware of the limitations we face and the compromises we must make with the current systems.



If the sampling frequency is too low, aliasing may occur.



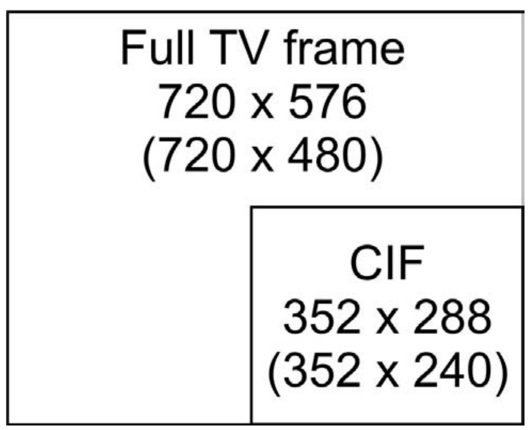
Left: TV field exported; Center: TV frame interlaced effect; Right: De-interlaced frame. Note the jagged edges on the car when field recording is used (left) and the quality of the same when frame recording is used (center and right).

The above is all true for horizontal resolution, but let us now talk about vertical resolution. In some system designs, vertical resolution is as important, especially when detecting and recognizing license plates, or faces at a distance.

The number of quantized levels in ITU-601 is chosen to be represented with 8 bits, that is, making a total of 256 levels ($2^8 = 256$). The reason for such a choice is very practical from an engineering point of view: **no CRT can reproduce any more than around 250 levels of gray, so there is no need to sample the analog video signal with more levels than this**. The 256 is chosen because it is a binary number, and as we know, in the digital world everything is represented with zeros and ones (i.e., with the binary numbering system).

In actual fact, with the ITU-601 recommendations we should be aware of some more "tricks in the bag." As was the case with the sampling frequency of 13.5 MHz that encompasses the whole signal, including the sync pulses, the ITU-601 recommends that 8 bits are used for representing all of the vertical details of the signal. We can think of the time as the horizontal details, since it deals with lines in the horizontal direction of the display.

So, ITU-601 suggests that out of the 256 combinations of 8 bits, the 0 and 255 are used for representing the syncs, which leaves 1 to 254 values to be used for video. The luminance level of black is given a value of 16 (binary 00010000) and



A comparison between full TV frame and a CIF size

the white level is given a value of 235 (binary 11101011). The value 128 is used to indicate that there is no chrominance in the signal.

As we mentioned earlier, the number of vertical pixels in a TV frame offered by the PAL system is 576, while in the NTSC this is 480, which corresponds to the actual number of active lines in each standard**.** It is important to remind the reader that each analog camera in CCTV generates interlaced video (50 fields/s and 29.97 fields/s). The interlaced video consists of TV fields displaced in time (1/50 s for PAL and 1/29.97 s for NTSC). Because of this when digitizing video with moving objects, the **interlaced effect** may show up when the recording is made in frame mode. **This is a natural TV effect – a result of the interlaced scanning**. **It is not an error on behalf of the digitization, as some may think**. The objects may seem blurred in the direction of movement, and the faster the object moves the more obvious this effect is.

Certain techniques called ***de-interlacing*** can minimize or completely eliminate this effect. Such functions are available in various photo editing programs (such as PhotoShop or PhotoPaint), but some dedicated DVR programs can also do it.



A full frame exported image from a DVR that uses wavelet compression



A full frame exported image from a DVR that uses MPEG-2 compression

The result of recording in frame mode, as opposed to field, is twice the vertical resolution, making object edges smoother and showing more details in an exported image (see the examples on this and the next page). When playing a footage recorded in frame mode, an artifact of playing alternating fields becomes apparent and this is the jumping up and down of each next field by one line. This is again a natural result of how interlace television works, and it is not an error in the playback as some may think. Basically, the digitized fields are displaced by one line (since they are coming from cameras complying with the 2:1 interlaced PAL or NTSC TV standard). When recording in frame mode, basically the DVRs record two fields, so the price paid for this is twice larger file sizes (since there are two fields used by the system to make up a frame).

It is interesting, then, to ask the following question: how does a digitized video recorded in field mode (720 × 288 for PAL, or 720 × 240 for NTSC) get reproduced to appear with 720 × 576, that is, 720 × 480 on a screen or when exported? **This is done simply by duplicating each line**. Such duplicating



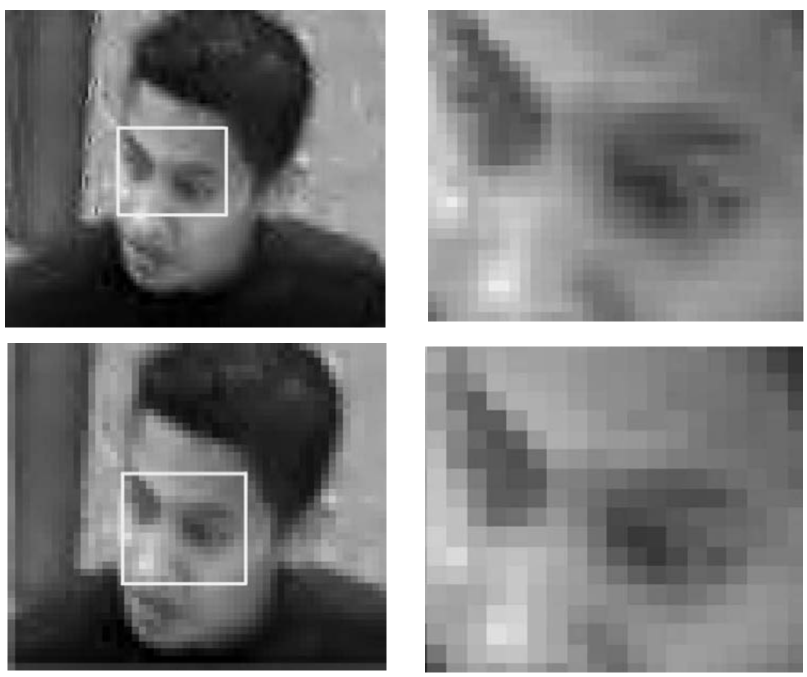
The difference between field recorded image on the left and the frame recorded

produces another prominent effect of ***jagged edges***. The human eye is more sensitive to resolution in the horizontal direction than in the vertical, and this is the reason perhaps why the majority of DVR systems in practice are set to record this way. In some systems, however, vertical resolution might be more important, so frame recording should be used. For other DVRs, it is simply not possible to record in any other than field mode as that could be the only option they have.

The interlaced effect explained above appears only when image compressions are of the JPG or Wavelet type, which, as will be explained later in this chapter, are compressions that work with static TV fields and will be treated as still images. In temporal video compressions, such as MPEGs and H.26x series, the interlaced effect is compensated by the process of motion prediction vectors; therefore this effect is not as noticeable.

An exported BMP from an actual thief (below) and the details obtained in full TV frame (top) and CIF (below)





All of the discussion we have had so far refers to the so-called full TV frame resolution. There are a number of compression techniques that use one-quarter of the pixels in a full TV frame (i.e., 352 × 288 or 352 × 240 pixels). This size is usually referred to as the ***Common Interchange Format*** (CIF) and is used typically by MPEG-1 and H.261 video compressions. The purpose is to reduce the digitized format to an acceptable minimum data streaming size, useful for video conferencing, and comparable to VHS image quality. When resolution is discussed in systems using MPEG-1, H.261, and others based on the CIF size, all of the calculations and picture resolution we have made earlier are applicable by halving these numbers. Thus, an **equivalent analog resolution that a CIF size image would have is around 220 TVL**. This makes the CIF image pixels real estate one-quarter of the full frame as defined by the ITU-601 recommendation (one-half of the horizontal number of pixels and one-half of the vertical number of pixels). For many applications this might be of sufficient quality and it does offer a better image update rate when recording or transmitting (since the size is one-quarter of what it would be in ITU-601). It is especially useful in video conferencing, which is the original application the CIF format was designed for. The CIF resolution, before compression, is comparable to the maximum resolution of an analog VHS video (240 TVL). This is important to consider when designing a system where face identification or license plates recognition are required. Some discussions and CCTV specifications refer to the full ITU-601 frame as 4CIF, indicating that the pixel count is four times the CIF size. Also, a QCIF size is available, which refers to Quarter CIF size (i.e., 176 × 144 pixels).

It is understandable that we want the best possible picture quality. But no matter what steps we take, **the compressed image cannot be of a better quality than the original**. The pixel count of a digitally recorded image of any CCTV camera, even if it is a full frame size, is only close to 415,000 picture elements for PAL and 345,000 for NTSC, at best. One can certainly appreciate the difference between a 400,000 and say a still image of a digital photo-camera with, for example, 4,000,000 pixels. So when you get a customer asking why he gets pixelization after he zooms into a digitized image exported from his DVR, the answer is simple: that is the number of pixels the digital image has. CCTV cameras produce images that are far inferior to images produced by a photographic camera, be that a film camera or a digital one, and therefore they cannot be compared. So when you set out to design a system where faces and license plates need to be recognized, the pixel count has to be taken into account. We will say a few more words near the end of this chapter about what current CCTV standards recommend for such systems.



Countless numbers of DVRs are available these days for digital CCTV.

The need for compression

In order to find the data streaming rate required for ITU-601 digitized video we can make some simple calculations. Multiplying the samples of each line (864 for PAL and 858 for NTSC) with the number of lines in the system (625 and 525), then with the number of TV frames of the system (25 and 30) and assuming 8 bits representation of luminance and 8 of the color differences (4 for Cr and 4 for Cb), we get approximately **the same bit rate for both digitized TV systems**.

For **PAL:** 864 × 625 × 25 × (8 + 8) = 216 Mb/s, of which the **active video streaming is 720 × 576 × 25 × 16 = 166 Mb/s.**

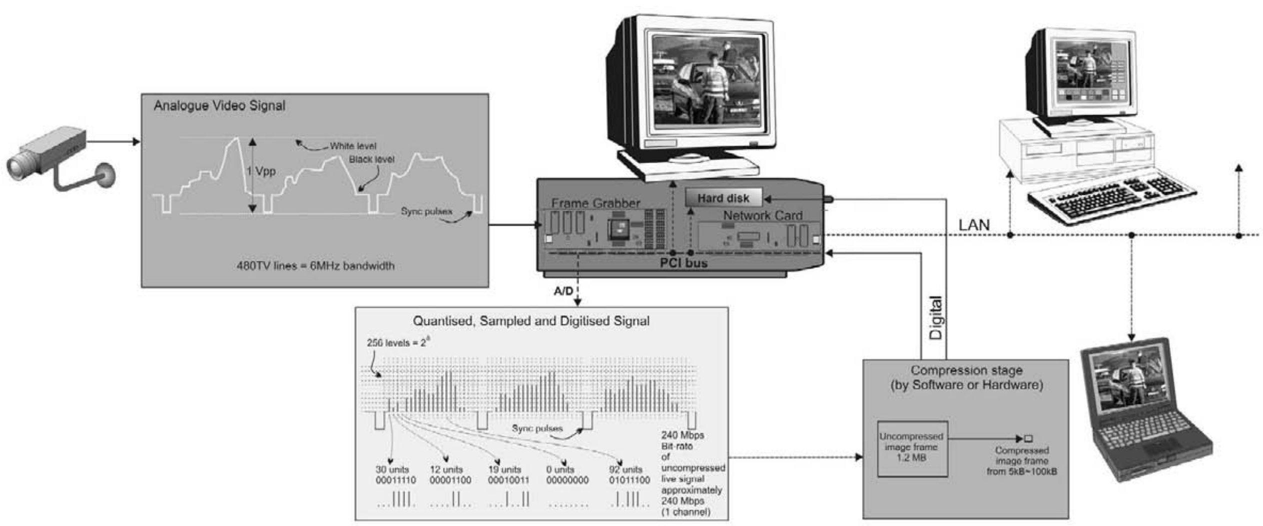
For **NTSC**: 858 × 525 × 29.97 × (8 + 8) = 216 Mb/s, of which, similarly, the **active video streaming is 720 × 480 × 29.97 × 16 = 166 Mb/s.**

This is a bit rate for a digitized noncompressed live video streaming, according to ITU-601 with 4:2:2. If the 4:4:4 sampling strategy is used, or even 10 bits instead of 8 bits sampling (which is done in the broadcast TV for video editing and processing), this number of over 166 Mb/s streaming becomes almost twice as big.

Such a streaming is impractically high since even a 100BaseT network will not have sufficient bandwidth to cope with only one live video, let alone multiple cameras, as we have them in CCTV. So the first and most important thing that needs to be applied to the digitized video signal is compression.

Digital CCTV would be impossible without video compression.

Various video compressions are used in broadcast television as well, on the Internet for video streaming, DVD recording and so on, but the CCTV industry makes most of it as it goes to the extreme with the compression technologies, often making best compromises between highest possible compressions and maximum picture quality. This is especially important when using multiple cameras into a typical DVR



Analog-to-digital conversion signal flow in a typical digital video recording system

(multiplexed recording with typically 16, 18, 24, or 32 cameras). There are a variety of techniques and standards, which offer different advantages.

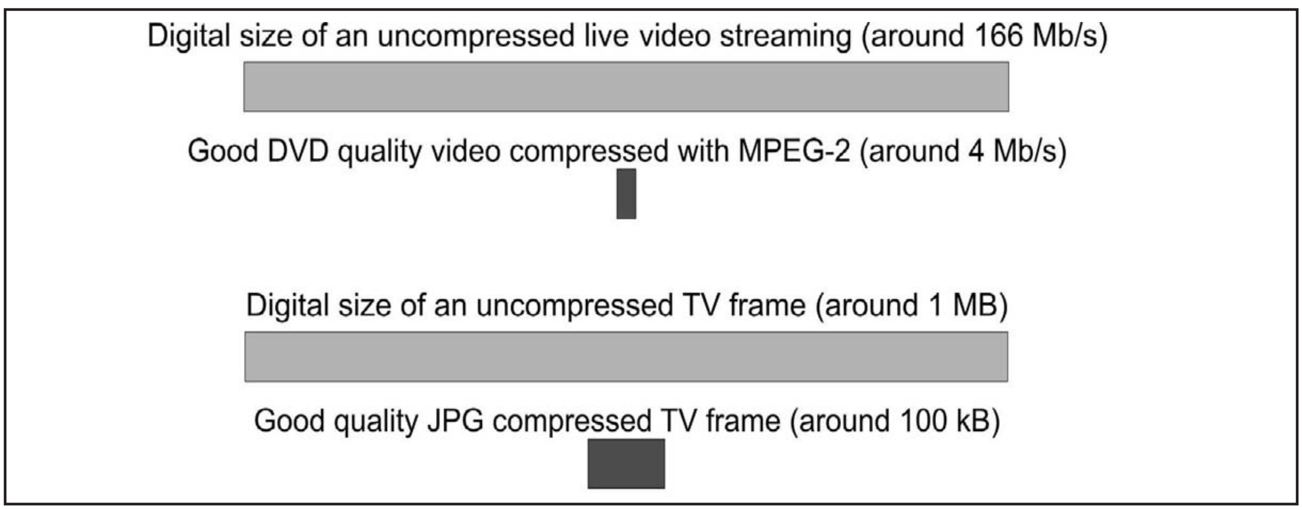
A typical noncompressed full frame video image can be over 1.244 MB in size in PAL (720 × 576 × 3 = 1.2 MB) where we assume 3 colors and 8-bit sampling. Hence 8 bits can be converted to 1 byte. In CCTV we work with a compressed image size of less than 100 kB, and often even lower than 10 kB.

When video compressions are used (instead of image compressions), the compression is not expressed in field or frame size in kB, but rather as a streaming in kb/s or Mb/s. So, for example, a high DVD quality video compression using MPEG-2 takes around 4 Mb/s. A decent quality of MPEG-4 streaming over the Internet can be around 256 to 512 kb/s. How far you can go in increasing the compression depends on how much detail one is willing to sacrifice from the image and the type of compression used, but, again, there is no doubt: **compression must be applied**.



A typical split screening, usually available for live viewing and playback of multiple cameras

It should be made clear that other video processing can be done on a digitized signal as well, before or after the compression. Some processing makes a simple division and recalculation in order to put the images in smaller screens (as is the case with split screen compressors or multiplexers), other processing may perform sharpening (which is actually an algorithm where every pixel value of the image is changed on the basis of the values of the pixels around it) or video motion detection, and still others may reduce the noise in the signal, and so on.



A graphical comparison between typical good-quality image and video compression ratios used in CCTV. Note the better efficiency of the MPEG-2 for the similar quality.

When a video signal is digitized and compressed, it is possible to store it (record it) or send it via a network, the Internet, or any other communication channel much more quickly. These are only some of the important flexibilities of digitized video which are impossible with the analog version of it.

The advantages of using digital networked CCTV are obvious: in many businesses, campuses or factories, networks are already in place. Providing there is a green light from the responsible IT people for using the corporate Local Area Network (LAN), the digital CCTV system can easily be retrofitted in such environments, and furthermore, the distances can be increased by simply joining adjacent LANs to form a Wide Area Network (WAN). It is quite obvious, in the age of the Internet that a local CCTV system can easily become a global large-scale system connecting continents as if they were a street across.

Local networks and network cables have their limitations as well (this is discussed in detail in the Networking chapter), and if longer distances are to be achieved, network repeaters are required (this is usually done by network switches and routers).

Many digital CCTV systems today are designed to make use of the Internet, and once we get on the Internet it seems as if there is no distance limitation since the Internet takes care of the repeaters and signal amplification needed to get from point A to point B, no matter how far apart they are.

Digital CCTV cameras are now also available (usually referred to as IP or LAN cameras) which can really bear this name since they can be plugged into the existing LAN and be accessed via a web browser using their IP address, as opposed to the digital signal processing (DSP) cameras we spoke about in Chapter 5, which produce analog composite video. Admittedly, IP cameras are still used mainly in smaller installations, in video conferencing over the Internet, or in industrial and specialized scientific applications. At today's stage of technology, the image quality and refresh rate of IP cameras is not as high as the same from analog cameras, but there is no doubt that the digital image processing and compression technology goes so fast forward that the time IP cameras can be compared with their analog counterparts will come.



Courtesy of Axis

A typical IP camera (there is no BNC at the back)

The data rate for a good-quality live video of multiple cameras could be very high even if it were compressed, and such a data rate would require better cables. More importantly, after talking to the IT people where such a system is put in place, it could also be found that most of them would have concerns about the data bandwidth consumed by such a digital CCTV. So very often we will be faced with a requirement for a digital CCTV system with controlled bandwidth, or even with its own dedicated LAN. Such an approach requires that we learn yet another new technology – ***networking***, ***TCP/IP*** concepts, and everything else you need to know when switching to digital. A chapter on this topic is also included in this latest book on CCTV.

So let us now describe each of the compression technologies as we see and use them in CCTV.

Types of compressions

CCTV has it all: JPEG, M-JPEG, Wavelet, H.263, MPEG-1, MPEG-2, JPEG-2000, MPEG-4, H.264, and so on. There are too many different image compression techniques. How do you know which one is best for you?

The answer is, without any doubt, not easy to find. One has to understand the concept of digitized images and the limitation of the TV standards, on top of which digitized video and compression limitations have to be added.

In general, there are two basic types of image/video compressions: ***loss-less*** and ***lossy***.

Loss-less offers very low compression ratios (usually not more than 3 to 4 times) and is generally not used in CCTV, but in broadcast and video editing. So, the compression types we will concentrate on in this book are the lossy ones. Lossy means that certain details of the image (video) are lost and cannot be retrieved, no matter what we do after they are compressed. **Good compression is** not the one that offers the highest squeeze, but **the one that offers the best compromise between quality and small file size**.

One of the most popular image compressions today is the JPG, used most often in digital photography. We all know it, have seen it, and have experienced that a typical JPG compression of up to 10 times hardly introduces any visible deterioration in the picture. So if you have a 4 Megapixel digital camera, for example, it would produce a noncompressed file size of around 12 MB. This is not a small size to work with and is not an easy task if we need to store more than a couple of such images on a typical 32 MB flash card. Yet, if we use just a normal JPG compression of 10 times, we get a bearable size of around 1 MB to work with and no noticeable losses. The problem in CCTV is that we usually want compressions even higher than 10 times. Do not forget that, as discussed in the previous heading, one noncompressed TV frame when digitized becomes a data packet of over 1 MB in size. A 10 times compression will make it around 100 kB file size, which some DVRs and IP cameras use, but very often the need for long storage pushes the demand for compression much further than this. It is not rare to hear manufacturers quoting 100 times compression per TV field. Common sense will tell you that many more details are lost when going to higher compressions, and furthermore some artifacts are introduced. Again, finding the best compromise between a decent quality and a small file size is the real answer. It is also fair to say that there are some smart and interesting solutions (usually proprietary) that make a good effort of getting further reduction in size by introducing some kind of temporal redundancy (static background, for example, of an image is not recorded again, but only the difference between the new image and the previous),



A good choice of compression, camera, and lens can show vehicle license plates clearly.



Noncompressed image (720 x 576 pixels) on the left (digitized and noncompressed around 1.2 MB) and the same on the right compressed 100X with JPG compression

which in a way is somewhat similar to the principles on which MPEG and H series compressions are based. But no matter what compression you decide to use, the source of your video signal, the camera, should have the best quality signal you can get. This means a good camera and a good lens. Only when the original video signal is optimized and shows good detail and color, can make your effort to have the digitized video be almost as good.

You cannot have, or reproduce, a detail in a digitally recorded picture if such a detail was not seen by the camera in the first place. This is a very basic and trivial statement, but very often I have seen security managers want to recognize a number plate in their digitally recorded image, which was not seen by the camera in the first place. So a simple rule of thumb would be: **a digitally recorded and replayed image cannot appear better than the original signal coming out of the camera.**

It is worthwhile investing in a good-quality camera and lens. A good-quality camera is the one with high-resolution CCD or CMOS chip, good signal/noise ratio, good dynamic range, low light performance, and a good lens. Based on practical experience, it should be noted that when using CCTV cameras for digital recording, **the signal/noise ratio is of high importance for the digitized image quality**. The resolution is important, but the low noise performance is probably even more important for the simple fact that when there is a too high noise content in the image the compression engine works around the noise speckles as if they were a useful content of the captured image. So, if your camera has a low S/N ratio (i.e., high noise content), after the compression the image will look worse than it appears while viewing it live. In simple words, the higher this ratio is (50 dB+), the better quality the digitized signal will be.

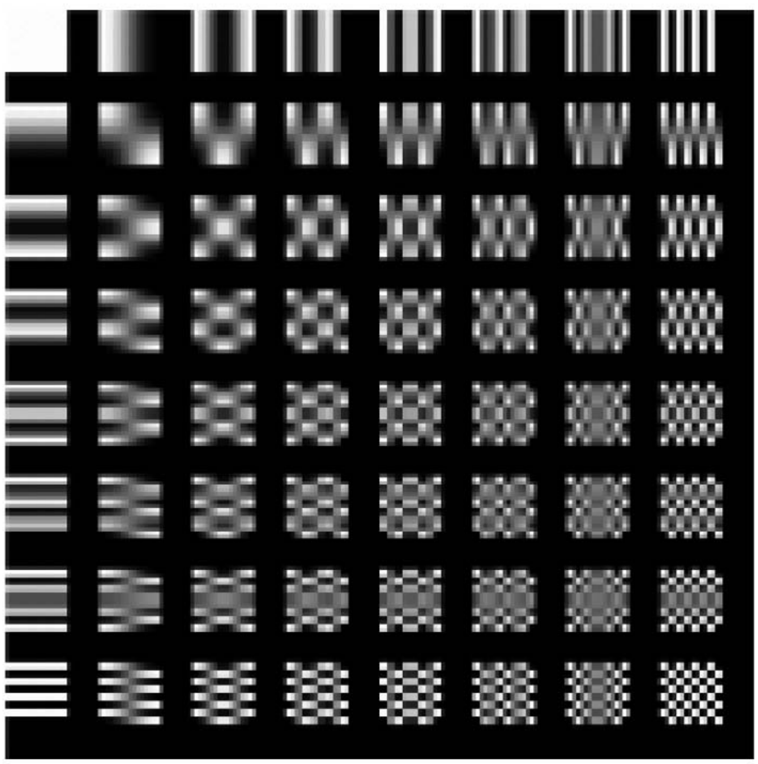
Once a good-quality analog signal is digitized, if it uses the ITU-601 recommendation it will be nearly as good as the original signal (assuming we are using the full TV frame resolution) after which the compression stage is the one that further reduces the picture quality. The compression stage is, in a way, a resolution bottleneck. **An important note should be made here not to confuse the number of pixels with the compression loss of resolution**. When using a full frame image capture and compression, the number of frame pixels will still stay the same, say 720 × 576, but the artifacts produced with the compression may change the picture resolution appearance. This is why we say that for a full TV frame video, the compression stage is a resolution bottleneck.

DCT as a basis

One of the most common mathematical transformations used on two-dimensional images is the ***Discrete Cosine Transformation*** (DCT). This is the basis for almost all compression techniques used in CCTV, with the exception of the Wavelet and JPEG-2000. So JPEG, MPEGs, and H series compressions all use DCT in one form or another. Because of this, it is important to say a few words about it.

The DCT is based on the ***Fourier Transformation***. The Fourier Transformation is a very good method for analyzing signals in frequency domain. The only "problem" is that it always works with an assumption of signals being periodical and infinite. This is never the case in reality and this is why an alternative to the Fourier Transformation, the ***Fast Fourier Transformation*** (FFT), was introduced in the 1960s. **The DCT is based on FFT**.

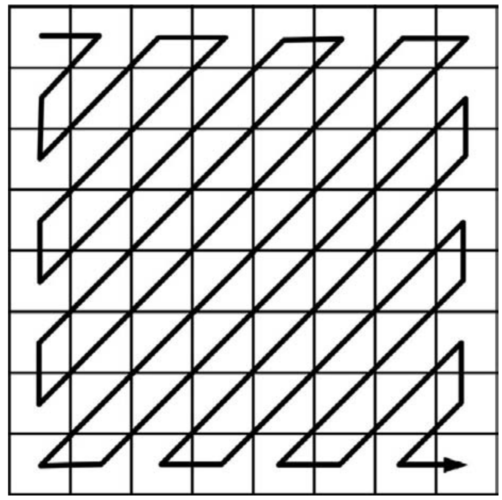
So how does the Discrete Cosine Transformation work? Spatial redundancy is found in all video material, be that CCTV or broadcast television. If there is a sizable object in the picture (TV field), all of the pixels representing that object will have quite similar values. This is redundancy, that is, it is possible to reduce the amount of information of each pixel with a value of the one giving the average and by defining the area only. Large objects produce low spatial frequencies, whereas small objects produce high spatial frequencies. Generally, these frequencies will not be present at a high level at the same time. Digitized video has to be able to transmit the whole range of spatial frequencies, but if a frequency analysis is performed, only those frequencies actually present need be transmitted. Consequently, an important step in compression is to perform a spatial frequency analysis of the image.



The Discrete Cosine Transformation principles

The illustration here shows how the two-dimensional DCT works. The image is converted a block at a time. A typical block is 8 × 8 pixels. The DCT converts the block into a block of 64 coefficients. A coefficient is a number that describes the amount of a particular spatial frequency that is present. In the figure the pixel blocks that result from each coefficient are shown. The top left coefficient represents the average brightness of the block and so is the arithmetic mean of all the pixels or the DC component. Going across to the right, the coefficients represent increasing horizontal spatial frequency. Going downwards, the coefficients represent increasing vertical spatial frequency. Now the DCT itself does not achieve any compression. In fact, the word length of the coefficients will be longer than that of

the source pixels. **What the DCT does is convert the source pixels into a form in which redundancy can be identified**. Because not all spatial frequencies are simultaneously present, the DCT will output a set of coefficients where some will have substantial values, but many will have values that are almost or actually zero. If a coefficient is zero, it makes no difference whether it is sent. If a coefficient is almost zero, omitting it will have the same effect as adding the same spatial frequency to the image but in the opposite phase. The decision to omit a coefficient is based on how visible that small unwanted signal would be, which is defined by the compression scale. If a coefficient is too large to omit, compression can also be achieved by reducing the number of bits used to carry the coefficient. This has the same effect as when a small noise is added to the picture. Some typical, and unwanted, artifacts when using DCT are the "blocky" appearance of the highly compressed images. This is due to the DCT function being applied to each 8 × 8 block of pixels.



The scanning pattern when doing Inverse DCT (IDCT) on blocks of 8 x 8 pixels

Readers should note that Wavelet compression is different compared to JPG in that Wavelet compression "looks at" the whole image, not blocks of 8 × 8, and hence Wavelet artifacts do not have such "blocky," but rather "foggy" appearance. In both DCT-based and wavelet-based compressions, there are losses, and this is why these compressions are called lossy compressions. The idea is to find the best compromise between a high compression in order to reduce file size and the best image quality without too much visible loss.



2X enlargement of a section 100X JPEG compression



2X enlargement of a section 100X wavelet compression

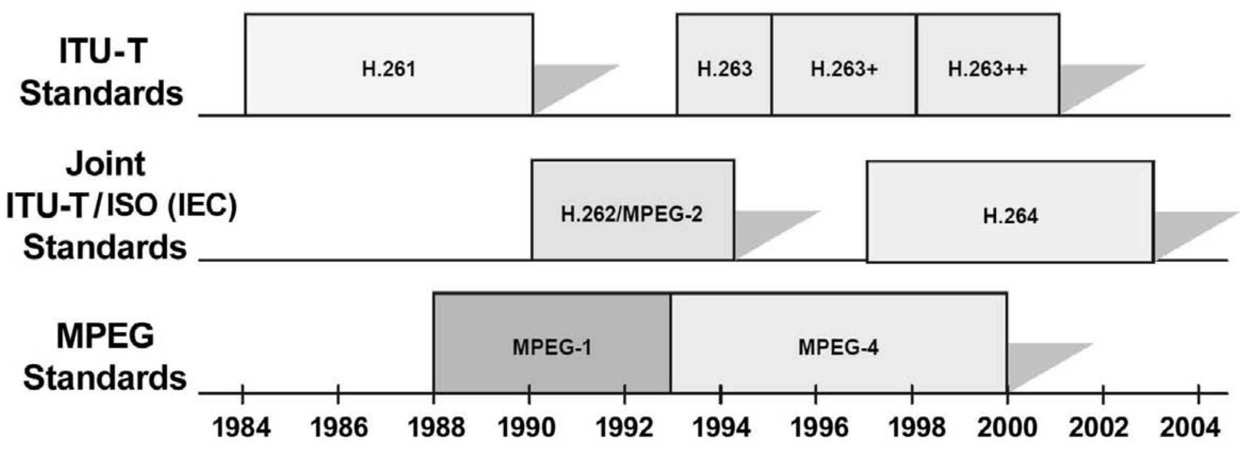
The variety of compression standards in CCTV

In CCTV we use a variety of video and image compressions, probably more than in any other industry. For example, in photography, JPEG is used most often when space saving has to be made. In broadcast television MPEG-2 is the dominant one, while on the Internet and in the computer industry, MPEG-4 has become a very common compression format.

In CCTV we find almost all types of compression in a variety of products. In order to understand them correctly, we should divide them into two main categories, as already explained in the previous few headings: compression applied to still images, which we call ***image compressions***, and compressions applied to a continuous streaming video signal, and therefore called ***video compressions***. The image compressions use static images, while the video compressions use the time as an important variable when reducing image redundancy and this is why video compressions are often referred to as ***temporal compressions***.

Each type has its own advantages, and often it is not easy to disregard one in favor of the other. Typically, image compressions are used on multiplex DVRs where multiple cameras are mixed and recorded onto a single set of drive. Some DVR manufacturers use two different compressions in the same machine, depending on the need. One could be for local recording, for example, and the other for remote transmission over narrow bandwidth communication channels where temporal compression might be more efficient. So it is important to understand them all and have an open mind and flexibility in respect to which one is to be used for a particular system.

Some authors make a compression division based on what standard group has proposed them, such as ITU-T or ISO. But of course there are many proprietary compressions that some manufacturers offer as their own, so we cannot really use such a division. Furthermore, new developments indicate that ITU-T and the ISO/IEC group will merge their work. They have basically agreed to have the ITU-T and the ISO/IEC JTC1 join their efforts in the development of the emerging H.264 standard, which was initiated by the ITU-T committee.



The time progression of various video standards and the ITU-T and ISO/IEC joint work

The following are the most common **image compressions** used in CCTV today, in the order of time appearance:

- JPEG – A widely spread standard, over 15 years in existence. Uses DCT type of compression. Incorporated and used by many programs, such as image editing and web browsers.

- M-JPEG – A variation on JPEG, and not really a standard. M-JPEG stands for Motion JPEG, where each image is an independently compressed TV field or frame using JPEG compression.

- Wavelet – A very popular image compression in CCTV. Offers better detail efficiency than JPEG as it does not divide the image in blocks of 8 × 8 pixels.

- JPEG-2000 – A standardized version of the Wavelet compression. Plug-ins are available for JPEG-2000 for a variety of image editing programs and web browsers.

- Motion JPEG-2000 – Similar to the M-JPEG, but this time using JPEG-2000 as a basis.

The following is the evolution of **video compressions**:

- H.261 – Low bit-rate technique introduced in 1984 by the ITU for audiovisual services.

- MPEG-1 – ISO standard, created as a modification of H.261 for the transfer of video onto CD at low bit rates (at around 1.5 Mb/s).

- MPEG-2 – Introduced for broadcast-quality video: uses lower compression levels to enable transfer of high-quality video. Today, used by majority of TV stations, DVDs, and cable television, and many DVR manufacturers.

- H.263 – An adaptation of MPEG-2 introduced to achieve higher levels of video compression while maintaining high picture quality. Adopted worldwide in 1996. It was revised in 1998. The H.263+ and H.263++ are enhanced versions of H.263.

- MPEG-4 – Developed as an object-based compression. There are a few versions of it. Handles compression of video and audio and a wide variety of streaming rates. Suitable for anything that uses narrow bandwidths, from mobile phones, the Internet, to television.

- MPEG-7 – New; defines an interoperable framework for content descriptions.

- MPEG-21 – New; describes the big picture of handling all objects in a variety of MPEGs.

- H.264 – Newest work based on H.263 and MPEG-4 (also called AVC), which offers a wide range of video quality, including more efficient coding for HDTV (quoted up to three times more efficient than MPEG-2).

So let us now analyze all of them separately.

JPEG

JPEG stands for ***Joint Photographic Experts Group*** of the ISO, which is the original name of the committee that prepares the digital photographic standard.

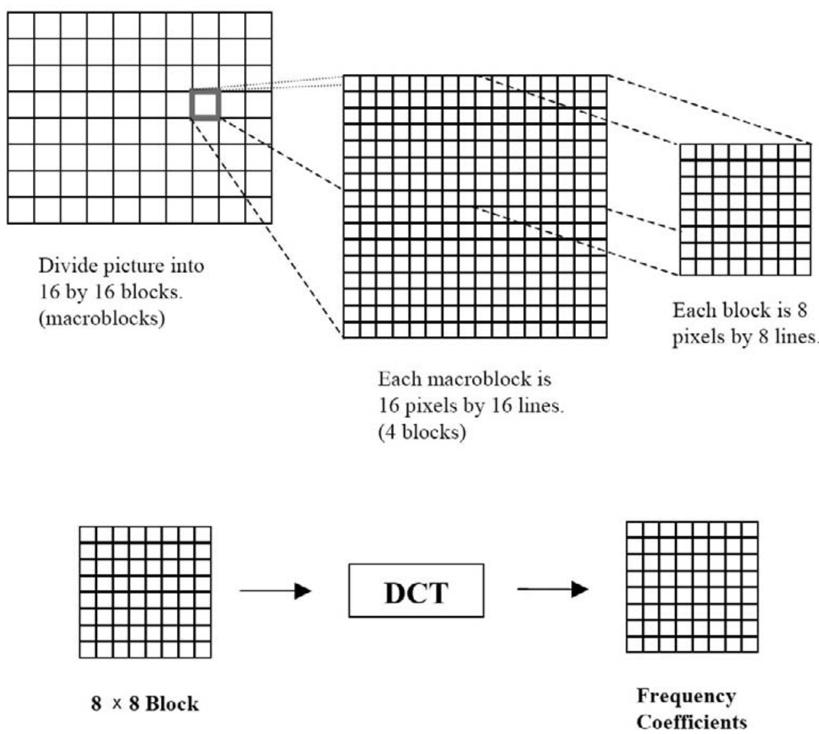
JPEG is also named the standardized image compression mechanism which uses DCT in order to reduce the image redundancy. It works only with still digital images, and resolution is not specified.

Although it is widely used in digital photography and web-based technology, we use JPEG in CCTV as well, where compression is applied to the digitized video (TV fields or TV frames), treating them as independent still snapshots.

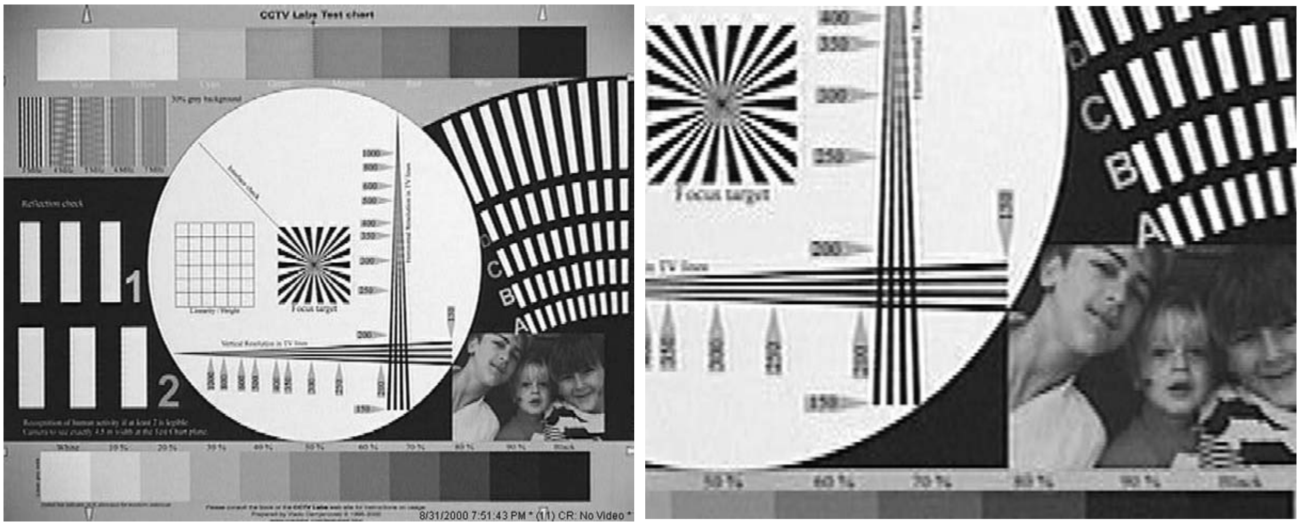
JPEG has a subgroup recommendation for loss-less compression (of about 2:1), but, as we mentioned earlier, in CCTV we are more interested in the lossy compression JPEG, where compression factors of over 10× are possible. JPEG works by transforming blocks of 8 × 8 picture elements using the discrete cosine transformation (DCT). The compression factors achieved with lossy JPEG compression are quite high (over 10 times), and the picture quality loss appears insignificant to the human eye.

JPEG is designed to exploit the known limitations of the human eye, like the fact that fine chrominance details are not perceived as well as fine luminance details in a given picture. For each separate color component, the image is broken into 8 × 8 blocks that cover the entire image. These blocks form the input to the DCT. Typically, in the 8 × 8 blocks, the pixel values vary slowly. Therefore, the energy is of low spatial frequency. A transformation that can be used to concentrate the energy into a few coefficients is the two-dimensional, 8 × 8 DCT. This transformation, studied extensively for image compression, is extremely efficient for highly correlated data.

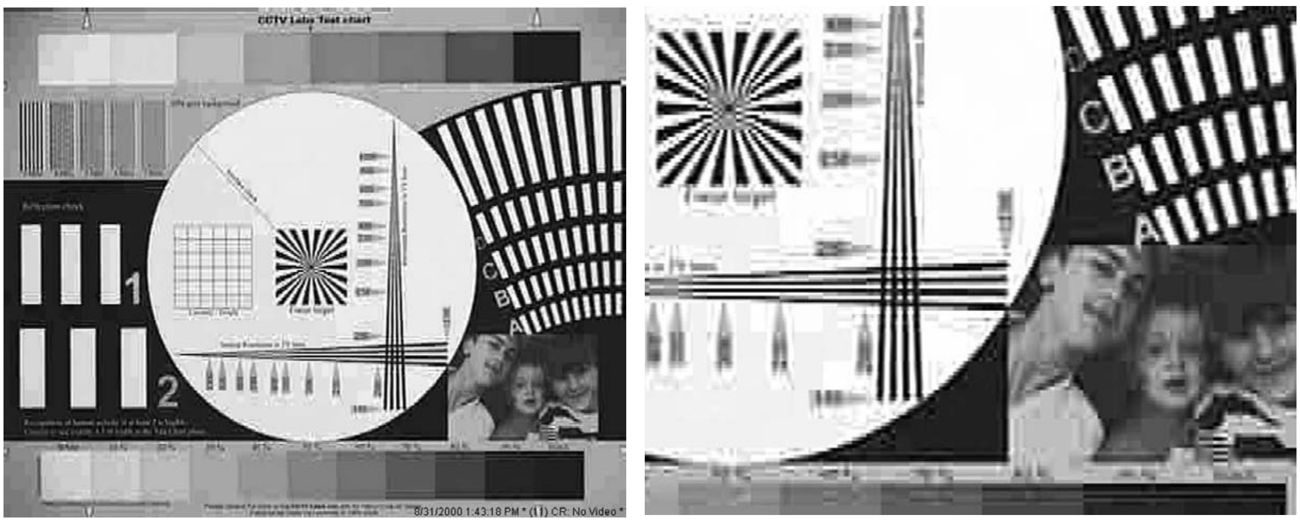
JPEG stores full-color information: 24 bits/pixel (16 million colors) compared to the ***graphics interchange format*** (GIF), for example (another popular compression technique among PC users), which can store only 8 bits/pixel (256 or fewer colors). Gray-scale images do not compress by such large factors with JPEG because the human eye is much more sensitive to brightness variations than to hue variations and JPEG can compress hue data more heavily than brightness data.



The DCT blocking used in JPEG



A 49 kB JPG TV field image of the CCTV Labs test chart; enlarged detail on the right



A 15 kB JPG TV field image of the CCTV Labs test chart; enlarged detail on the right

An interesting observation is that a gray-scale JPEG file is generally only about 10 to 25% smaller than a full-color JPEG file of similar visual quality. Also, it should be noted that JPEG is not suitable for line art (text or drawings), as the DCT is not suitable for very sharp B/W edges.

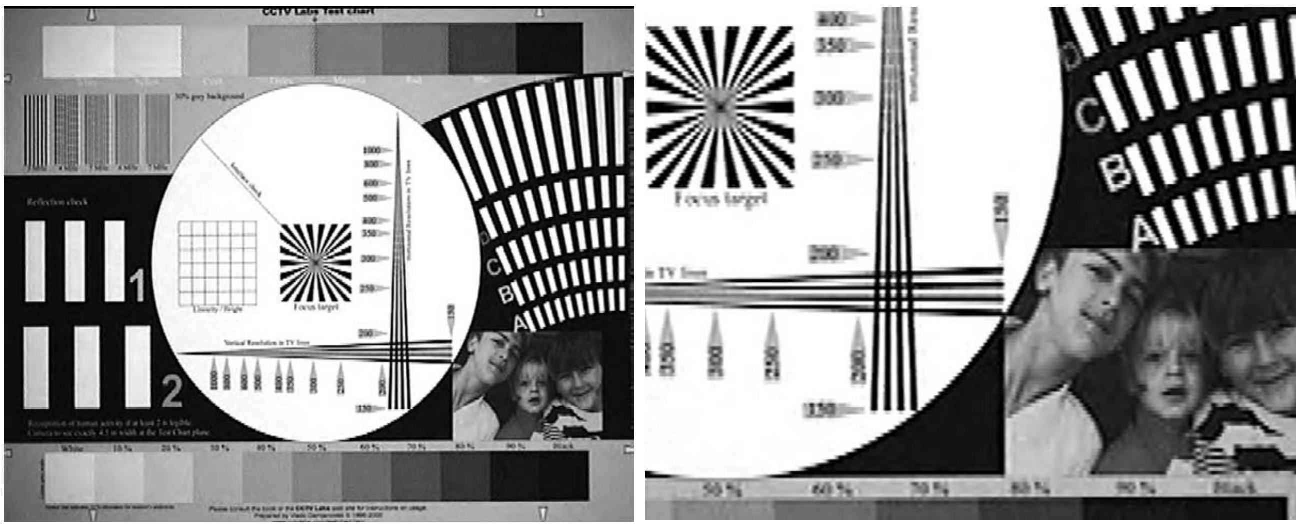
JPEG can be used to compress data from different color spaces such as RGB (video signal), YCbCr (converted video signal), and CMYK (images for the printing industry) as it handles colors as separate components. The best compression results are achieved if the color components are independent (noncorrelated), such as in YCbCr, where most of the information is concentrated in the luminance and less in the chrominance.

Since JPEG files are independent of each other, when used in CCTV recording, they can be easily played back in reverse direction. Playback speed can be increased or reduced and copied as single files or groups of files.

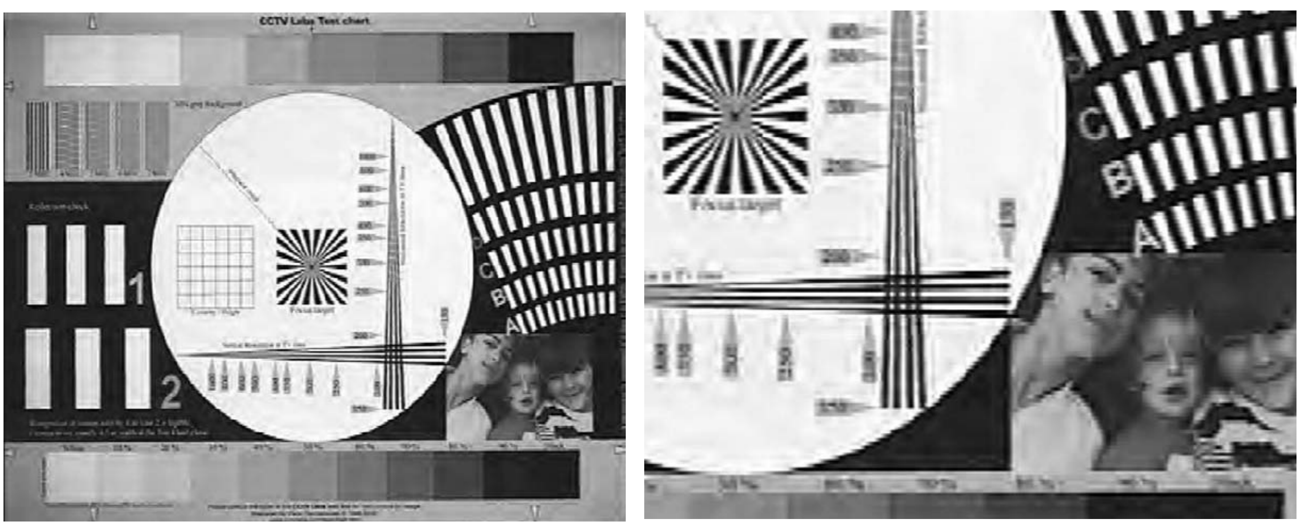
M-JPEG

Motion JPEG (or M-JPEG) is a JPEG derivative typically used in CCTV only. M-JPEG does not exist as a separate standard but rather it is a rapid flow of JPEG images that can be played back at a sufficiently high rate to produce an illusion of motion. Because the relation between individual frames is not taken into account in M-JPEG, this method achieves relatively low compression rates compared to the temporal compressions, such as the H.26x or MPEG described later. However, M-JPEG is used by some DVR manufacturers where multiple cameras are used.

The M-JPEG method is not internationally standardized, and JPEG does not include a transmission standard. The implementations of different manufacturers are therefore incompatible. As a variation, the difference between consecutive images is often also coded with the JPEG method to achieve a further reduction in the volume of data. This differential frame method is also not standardized, so that the decoder of the same manufacturer is required for decoding.



A 45 kB Wavelet field image of the CCTV Labs test chart; enlarged detail on the right

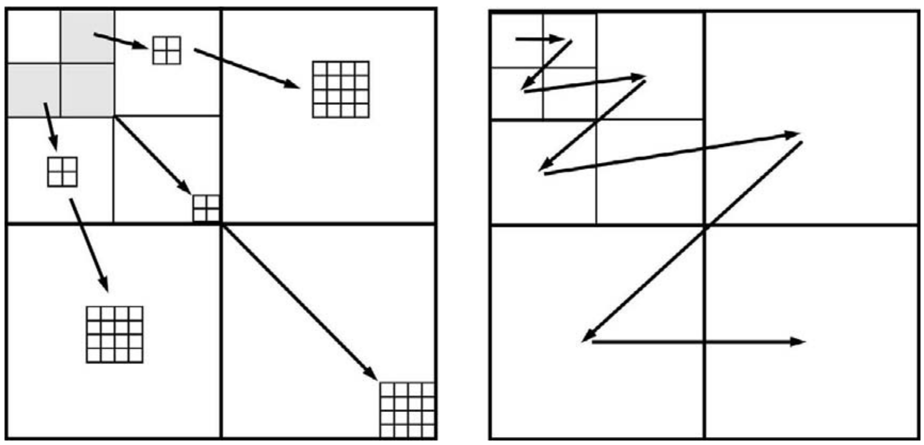


A 15 kB Wavelet field image of the CCTV Labs test chart; enlarged detail on the right

Wavelet

For many decades, scientists have wanted more appropriate functions than the sines and cosines that comprise the bases of DCT's Fourier analysis to approximate choppy signals. By their definition, sines and cosines are nonlocal functions (they are periodical and stretch out to infinity). This is the main reason they do a very poor job of approximating sharp changes, such as high-resolution details in a finite, two-dimensional picture. This is the type of picture we most often have in surveillance time-lapse multiplexed recording, as opposed to a continuous stream of motion images in broadcast television. Wavelet analysis is one that works differently, and **it is more efficient in preserving the small details**.

The wavelet mathematical apparatus was first explicitly introduced by Morlet and Grossman in their works on geophysics during the mid-1980s. As a result, wavelet compression was first used in scientific data compression such as astronomy and seismic research. It was soon discovered that it would be extremely useful in CCTV, when Analog Devices wavelet compression chip 601 was introduced. Wavelet compression transforms the entire image as opposed to 8 × 8 sections in JPEG and is more natural as it follows the shape of the objects in a picture. This is why wavelet has become especially attractive for CCTV.



One of the clever wavelet ways of coding a picture and reducing the redundancy by a zig-zag method

With wavelet we can use approximating functions that are contained in finite domains. Wavelets are functions that satisfy certain mathematical requirements and are used in representing data or other functions in wavelet analysis. The main difference compared to the FFT (DCT) analysis is that the **wavelets analyze the signal at different frequencies with different resolutions**, i.e., many small groups of waves, hence the name wavelet. The wavelet algorithms process data at different scales or resolutions and try to see **details and the global picture**, or as some wavelet authors have said, "see the forest and the trees" as opposed to Fourier analysis which "sees just the forest."

Wavelets are well suited for approximating data with sharp discontinuities. The wavelet analysis procedure is to adopt a wavelet prototype function, called an analyzing wavelet or mother wavelet. Time analysis is performed with a contracted, high-frequency version of the prototype wavelet, whereas frequency analysis is performed with a dilated, low-frequency version of the prototype wavelet. Because the original signal or function can be represented in terms of a wavelet expansion (using coefficients in a linear combination of the wavelet functions), data operations can be performed using just the corresponding wavelet coefficients.

Another interesting feature of wavelet is the “Area of Interest” or “Quality Box” function, where an image presence can be detected based on motion, for example, and have that area compressed with better quality relative to the rest of the same image. By using such an intelligent selection, the file size is extremely small, yet offers best details where the important object is.



Wavelet chips offer a so-called Area of Interest or sometimes called Quality Box, shown on the right.

JPEG-2000

JPEG-2000 (ISO 15444) is basically a standardized version of the wavelet compression, produced by the JPEG group. At the time when wavelet compression chips were introduced by Analog Devices, back in the 1990s, there was no common or standardized wavelet file format. The JPEG group realized the superiority of wavelet and started working on a new standard for image compression. Its release was scheduled for the year 2000, hence the name JPEG-2000.

The JPEG-2000 standard makes way for wide usage of the wavelet compression with full compatibility between various products and programs. Many software plug-ins and hardware compression chips can be found today, and images can be exchanged between various platforms. It is possible to download a JPEG-2000 PhotoShop or web-browser plug-in from the Internet for example. Some photo editing programs such as Corel Photo Paint and JASC Paint Shop Pro already embed a JPEG-2000 codec. This is the purpose of standardization, to have an exchangeable file format between a variety of programs. Many manufacturers now have JPEG-2000 hardware codec chips in their range of products.

Furthermore, the JPEG-2000 standard defines usage of embedded information about the author or source of the image, or, what is interesting for us in CCTV, the originality of the image. There are some variations of JPEG-2000, one of which refers to motion video and is called Motion JPEG-2000.



The new Analog Devices ADV202 chip uses JPEG-2000 and promises a lot, both in HDTV and CCTV.

Motion JPEG 2000

Motion JPEG-2000 is new, and although not used in CCTV yet, it is mentioned here as a highly flexible and promising format. Because of the wavelet scalability, Motion JPEG can reproduce any size video frame rate on the fly, from the same video stream. This is ideal for full-frame local storage along with subresolution transmission over narrow bandwidth. Motion JPEG-2000 uses only key frame (TV fields) compression, allowing each frame to be independently accessed. Key frame compression provides the extremely accurate frame-by-frame time stamps needed for surveillance and evidentially procedures. This is important for multiplexed recording in CCTV, but also for video editing. Real-time encoding allows video to be compressed at capture time, enabling more efficient storage on and higher quality video transmission over a network or the web.

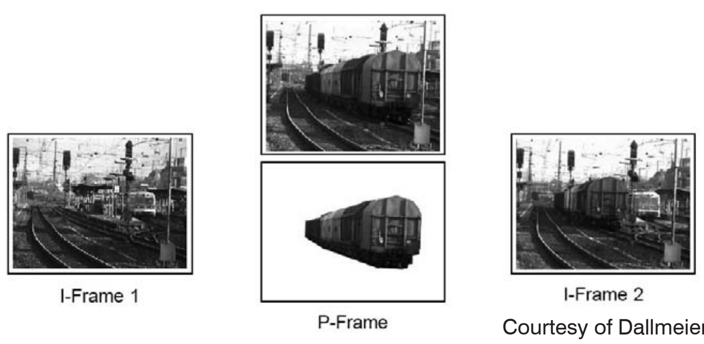
MPEG-1

MPEG-1 (ISO 11172) is one of the first video compression standards, proposed by the ISO's ***Motion Picture Experts Group*** soon after the introduction of the H.261. It belongs to the video compression group; it works with continuous digitized video signal and includes two channels of audio. **The output visual quality at typical bit rates (as used in VCDs, for example) is comparable to that of an analog VHS VCR. The audio layer of MPEG-1 is the actual, now popular, audio format MP3.**

MPEG-1 is defined to work with CIF size (352 × 288 for PAL; 352 × 240 for NTSC source) video sequence. The color information is sampled with half of that resolution: 176 × 144 (i.e., 176 × 120). Typical video rates MPEG-1 works with are between 1 Mb/s and 3 Mb/s. Around 1.5 Mb/s is a data speed achievable by majority CD players in the time when MPEG-1 was introduced, and this was one of the major applications for the MPEG-1 video compression. Up to one hour can be stored on a CD of 700 MB, which is the reason two CDs were needed for VCD movies.

MPEG does not define compression algorithms (although it is based on DCT), but rather the compressed bit stream – the organization of digital data for recording, playback, and transmission. The actual compression algorithms are up to the individual manufacturers, and their quality may vary.

The basic idea in all temporal compressions is to predict motion from frame to frame in the temporal direction and then to use the DCT to organize the redundancy in the spatial directions. The DCTs are done on 8 × 8 blocks, and the motion prediction is done in the luminance (Y) channel on 16 × 16 blocks. In other words, the block of 16 × 16 pixels in the current frame is coded with a close match to the same pixel block in a previous or future frame. This describes the backward prediction mode, where frames



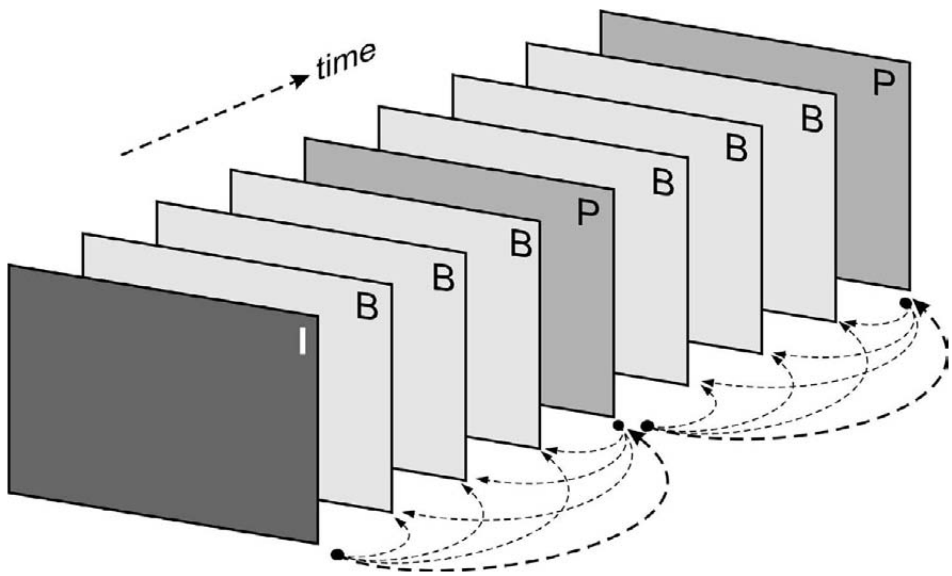
Courtesy of Dallmeier

An extremely simiplified representation of how predicted pictures are calculated from I

coming later in time are sent first to allow interpolating between frames. The DCT coefficients (of either the actual data or the difference between this block and the close match) are quantized, which means that they are divided by some value to drop bits off the bottom end. Hopefully, many of the coefficients will then end up being zero. The quantization can change for every "macroblock" (a macroblock is 16 × 16 of Y and the corresponding 8 × 8's in both U and V). The results of all of this, which include the DCT coefficients, the motion vectors, and the quantization parameters (and other stuff), are encoded using the so-called Huffman code, using fixed tables.

There are three types of coded frames (pictures) in MPEG-1 (the same applies to MPEG-2): the ***intra frames*** **(I)**, ***predicted frames*** **(P),** and the ***bidirectional frames*** **(B)**.

The I pictures are basically still pictures compressed as JPG, and they are used as reference pictures (frames). The P pictures are predicted from the most recently reconstructed I or P frame. Each macroblock in a P frame can either come with a vector and difference DCT coefficients for a close match in the last I or P, or it can just be "intra" coded (as in the I frames) if there was no good match. The B pictures are predicted from the closest two I or P pictures, one in the past and one in the future. This is why they are called bi-directional, referring to using the past and "future" images. By the way, **this is the source of the known delay (latency) associated with the MPEG encoding.**



The Group of Pictures (GOP) interrelation in MPEG (a GOP size 9 is shown above)

The combination of I, P, and B pictures in MPEG is called a Group of Pictures (GOP).

If a GOP is composed of only one image, that would be only the I frame, and functionally it would be equivalent to Motion-JPEG. There is no temporal redundancy (saving) in such a case. When GOP gets around 12 or 15, it achieves the best compromise between a good compression and not too large latency.

A typical GOP sequence of 9, which always repeats itself, would look like this:

IBBBPBBBP IBBBPBBBP IBBBPBBBP...

Latency is a new side effect of the MPEG efforts to reduce redundancy by motion prediction. This is the price MPEG is paying for getting better picture quality at lower data rates. Most of the MPEG machines offer a choice of bit rates and GOP sizes – a combination of which can be selected to reduce the latency to below noticeable levels by choosing higher bandwidth and smaller GOP sizes. Basically, the number of pictures in a GOP define the latency. So if, for example, we have a GOP size of 12, in PAL this makes a half a second in time, which becomes such a delay. If we add to this delay the network latency, it becomes clear why a latency of nearly a second or even more is sometimes noticeable in MPEG coding.

The latency may not even be noticed in a fixed camera CCTV system, but clearly this could be a problem with PTZ camera control. So what is the acceptable latency when controlling a live video camera over LAN and MPEG streaming? This really is defined by the human reaction speed. When driving a car, for example, around 200 ms is taken as the fastest reaction a person can have. So, if we use this as a guide, it will make practically acceptable latency time.

Another interesting, but positive, side effect of the bidirectional macroblock prediction is noise reduction because of the averaging.

The practical application of MPEG-1 is most often in storing video clips on CD-ROMs, but is also used in cable television and video conferencing. There are, however, some digital recorders designed especially for CCTV applications where real-time video is recorded using MPEG-1 technique. In these applications, real-time video is more important than high-resolution video at a lower rate. The majority of higher quality MPEG-2 recorders are backwards compatible with MPEG-1 and can record and play back video streaming made in MPEG-1.

MPEG-2

MPEG-2 (ISO 13818) is not a next generation MPEG-1 but rather another **standard targeted for higher quality digital video with audio**. It was proposed by the ISO's MPEG group in 1993, and, like MPEG-1, MPEG-2 is also an Emmy Award-winning standard. **The MPEG-2 standard specifies the coding formats for multiplexing high-quality digital video, audio, and other data into a form suitable for transmission or storage.**

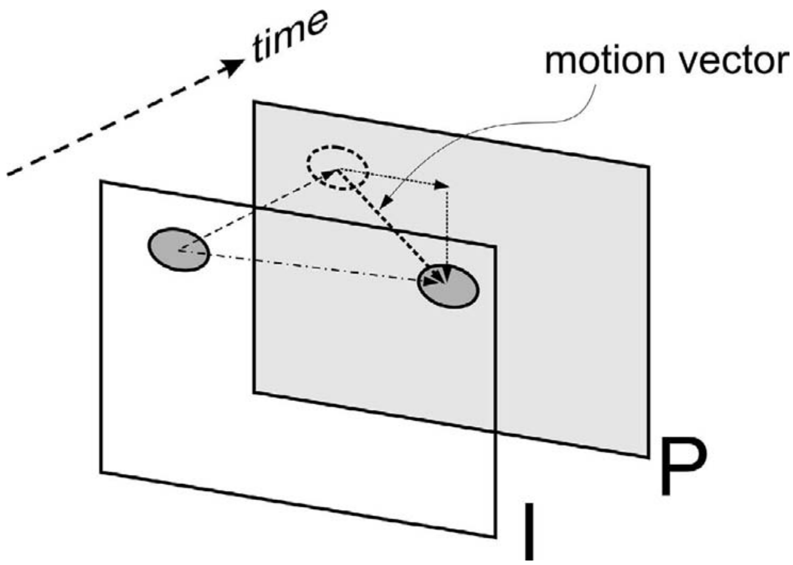
MPEG-2 Levels	Resolution	Typ. bit rate	Usage
Low	352 x 288 x 25 352 x 240 x 30	1.5 Mb/s	CIF size, CDs, some DVRs
Main	720 x 576 x 25 720 x 480 x 30	4 Mb/s	ITU-601, SDTV, many DVRs
High 1440	1440 x 1152	12 Mb/s	4 x ITU-601, consumer HDTV
High	1920 x 1080	20 Mb/s	HDTV Production SMPTE 240 standard

MPEG-2, like MPEG-1, does not limit its recommendations to video only, but also includes audio. It should be highlighted again that **MPEG-2 is not a compression scheme or technique**, but rather a standardization of handling and processing digital data in the fastest and most optimized way. MPEG-2 encoding can produce data rates well above 18 Mb/s, although in most practical CCTV applications there is hardly any visible difference between a live camera signal and its 4 Mb/s encoded video.

MPEG-2 is designed to support a wide range of applications and services of varying bit rate, resolution, and quality. The MPEG-2 standard defines four profiles and four levels for ensuring the interoperability of these applications. The profile defines the color space resolution and scalability of the bit stream. The levels define the maximum and minimum for image resolution, and Y (Luminance) samples per second, the number of video and audio layers supported for scalable profiles, and the maximum bit rate per profile.

As a compatible extension, MPEG-2 video builds on the MPEG-1 video standard by supporting interlaced video formats and a number of other advanced features. MPEG-2 today is used in almost all broadcast television services, such as DBS (direct broadcast satellite), CATV (cable television), HDTV (high-definition television), and of course the now popular movie format – DVD. A single-layer, single-sided DVD has enough capacity to hold two hours and 13 minutes of high-quality video, surround sound, and subtitles.

Like MPEG-1, the MPEG-2 is based on GOPs made up of I, P, and B pictures. The I pictures are **intracoded**, that is, they can be reconstructed without any reference to other pictures. The P pictures are forward predicted from the last I picture or P picture, that is, it is impossible to reconstruct them without the data of another picture (I or P). The B pictures are both forward predicted and backward predicted from the last and next I pictures or P pictures, that is, there are two other pictures necessary to reconstruct them. Because of this, P pictures and B pictures are referred to as **intercoded** pictures.



Motion vectors are used to predict the movement of objects between I and P frames.

In its prediction algorithm, MPEG-2 works with motion vectors. Imagine an I frame showing a circle on white background. A following P frame shows the same circle but at another position. Prediction means to supply a motion vector, which declares how to move the circle on an I frame to obtain the circle in a P frame. This motion vector is part of the MPEG stream and it is divided in a horizontal and a vertical part. These parts can be positive or negative. A positive value means motion to the right or motion downwards, respectively. A negative value means motion to the left or motion upwards. But this model assumes that every change between frames can be expressed as a simple displacement of pixels. There is also a prediction error matrix in MPEG stream, which helps in accurate reconstruction

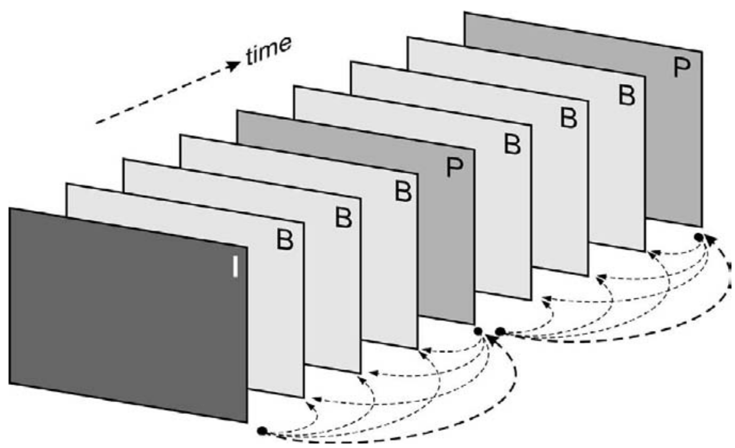
of the motion.

In the beginning of the CCTV digital era (only half a dozen years ago), only a very few DVR manufacturers were using MPEG-2. Today many more see the benefits of high-quality digital video recording, and many more unexplored MPEG-2 functionality are used in CCTV. For example reverse playback, slow play forward or in reverse direction, as well as the incredible fast forward or rewind speed of up to 1024 times the normal speed and even video motion detection triggered recording.

Admittedly, MPEG-2 is not designed to work with multiple cameras as there will hardly be any use of the temporal redundancy in that case. So, a DVR working with MPEG-2 video compression will usually stream a single-camera digitized signal to a hard disk, but some manufacturers have models where multiple channels are streamed concurrently onto the same hard drive. Clearly, when knowing the video data rate for a good quality video, for example, 4 Mb/s, it can easily be calculated that with today's hard disk technology it is possible to have quite a few channels in one box, even if we allow for simultaneous playback of the same drive.

Although MPEG-2 encoding can be done in the software, with reasonably fast processors, in CCTV it is always preferable to have this done by dedicated hardware compression chips, so at least the encoding (recording) is not compromised and there are no gaps in it. Decoding (playing back) can be made via software decoders, and there are quite a few around, since MPEG-2 is a standard. Windows Media Player, Apple Quick Time, Real Audio, and so on, are all examples of software players capable of playing the MPEG-2. With some MPEG-2 DVRs it is possible to burn a CD or DVD with MPEG-2 footage, which can be directly played onto a commercial DVD player.

Many high-end DVR manufacturers offer hardware encoding (recording) while doing hardware decoding on a composite or Y/C monitor, as well as software decoding of the same machine from another point in time in the past (usually referred to as Time Shift technology) for playback or backup over network. This multiple functionality sometimes is referred to as triplex, quad-plex, or penta-plex operation. In the latter case the following five functions would be performed concurrently: continuous recording, playback a certain instance from the past on a composite monitor, export a footage from the past on local external drive or CD, for example, playback another instance from the past via network on a PC, and back up to another PC or network storage via network, all at the same time. If all these processes are coming out of, or being written to, the same hard disk (which would usually be the case), then the hard drive data transfer rate needs to be able to sustain such a speed. This is one important reason some manufacturers prefer to to have a single channel MPEG-2 DVR rather than multiple channels in one box.



The same GOP idea is used in MPEG-2 as in MPEG-1.

MPEG-2 is suitable for any security application because it offers the best picture quality, but it is most often used in projects and systems where quick activities are typical, such as casinos and banks. Considerations have to be made when PTZ cameras need to be controlled over LANs with MPEG-2 and latency taken into account, but as mentioned earlier, this can be reduced to around 200 ms, or less, with the bit rate and GOP size smart adjustments.

It is fair to mention that because of the high data rate it uses, MPEG-2 is not suitable for remote and narrow bandwidth communications. Many manufacturers offer MPEG-4 as an add-on compression for such applications, since MPEG-4 is more flexible and is designed to make a maximum of narrow bandwidths, such are Internet DSL upload speeds of 128 kb/s, 256 kb/s, or more.

MPEG-4

MPEG-4 (ISO 14496) is another MPEG standard developed only recently. It is so recent that it was not even practically used before the previous edition of this book was published five years ago.

MPEG-4 is the result of another international effort involving hundreds of researchers and engineers from all over the world. MPEG-4, whose formal ISO/IEC designation is ISO/IEC 14496, was finalized in October 1998 and became an International Standard in the first months of 1999.

The MPEG-4 visual standard is developed to provide users a new level of interaction with visual contents. It provides technologies to view, access, and manipulate objects rather than pixels, with great error robustness at a large range of bit rates. Application areas range from digital television and streaming video to mobile multimedia, games, and of course CCTV and surveillance.

A major difference between MPEG-4 and the previous audiovisual standards, is the object-based audiovisual representation model. An object-based scene is built using individual objects that have relationships in space and time, offering a number of advantages. The MPEG-4 standard opens new frontiers in the way users will play with, create, reuse, access, and consume audiovisual content. The MPEG-4 object-based representation approach where a scene is modeled as a composition of objects, both natural and synthetic, with which the user may interact, is at the heart of the MPEG-4 technology. The handling of objects (especially the synthetic ones) and the interactivity are the heart of MPEG-4, which unfortunately in CCTV we cannot make any use of.

Motion compensation is block based, with appropriate modifications for object boundaries. The block size can be 16 × 16, or 8 × 8, with half pixel resolution. MPEG-4 also provides a mode for overlapped motion compensation. Texture coding is based in 8 × 8 DCT, with appropriate modifications for object boundary blocks. Coefficient prediction is possible to improve coding efficiency. Static textures can be encoded using a wavelet transform. Error resilience is provided by resynchronization markers, data partitioning, header extension codes, and reversible variable-length codes. Scalability is provided for both spatial and temporal resolution enhancement. MPEG-4 provides scalability on an object basis, with the restriction that the object shape has to be rectangular. This is perhaps one of the most useful features for us in CCTV, for it allows scalable streaming over narrow bandwidths.

The MPEG-4 visual standard has been explicitly optimized for three bit-rate ranges: below 64 kb/s, 64 to 384 kb/s, and 384 to 4 Mb/s.

MPEG-4 Video offers technology that covers a large range of existing applications as well as new ones. The low bit rate and error-resilient coding allows for robust communication over limited rate wireless channels, useful for mobile videophones, space communication, and certainly, CCTV. At high bit rates, tools are available to allow the transmission and storage of high-quality video suitable even for studio and other very demanding content creation applications. The standard has evolved through many versions, and support data rates beyond those of MPEG-2.

A major application area, outside our industry, is interactive web-based video. Software that provides live MPEG-4 video on a web page are very common.

MPEG-4 provides support for both interlaced and progressive (although progressive scan is rarely used in CCTV) video material. The chrominance format that is supported is 4:2:0. In this format, the number of Cb and Cr samples are half the number of samples of the luminance samples in both horizontal and vertical directions. Each component can be represented by a number of bits ranging from 4 to 12 bits.

As with MPEG-2, the MPEG-4 standard refers to a number of different Profiles. The MPEG-4 conformance points are defined at the Simple Profile, the Core Profile, and the Main Profile. The Simple Profile and Core Profile address typical scene sizes of QCIF and CIF size, with bit rates of 64 kb/sec, 128 kb/s, 384 kb/s, and 2 Mb/s. The Main Profile addresses a typical scene sizes of CIF (352 × 288), full standard definition ITU-R 601 (720 × 576), and High Definition (1920 × 1080), with bit rates at 2 Mb/s, 15 Mbit/s, and 38.4 Mb/s.

MPEG-4 is constructed as a toolbox rather than a monolithic standard, using profiles that provide solutions in these different settings. Although MPEG-4 is a rather big standard, it is structured in a way that solutions are available at the measure of the needs. It is the task of each implementer to extract from the MPEG-4 standard the technological solutions adequate to his needs, which are very likely a small subset of the standardized tools.

MPEG-4 recorders are becoming more popular in CCTV, although they may not necessarily use the same profiles, therefore, it should not be assumed that they are of the same visual quality.

MPEG-4 does not replace, as some may think, the MPEG-2, but it does offer wider flexibility in lower bit rates and it does offer near live video transmission over 256 kb/s and better. Some manufacturers even include MPEG-4 in their DVRs just for the purpose of remote connectivity and control, while still using other compressions for the local recording.

New standard works by ITU-T and ISO are under way where the latest version (profile) of MPEG-4 and H.264 is supposed to bring new compressions levels where HDTV movies can be squeezed on a high-capacity DVD suitable for HDTV movies and high-quality music.

MPEG-7

Although MPEG-7 and MPEG-21 (described briefly further in the text) are not the kind of video compressions we are used to in CCTV, it is important to mention them here, because they go one step further than compression. MPEG-1 and MPEG-2 provide interoperable ways of representing audiovisual content, commonly used in broadcast television, video editing, and CCTV as well. MPEG-4 extends this to many more application areas through features like its extended bit-rate range, its scalability, its error resilience, its seamless integration of different types of objects in the same scene, its interfaces to digital rights management systems, and its powerful ways to build interactivity into content.

MPEG-7 defines an interoperable framework for content descriptions way beyond the traditional "metadata." MPEG-7 has descriptive elements that range from basic signal features like colors, shapes, and sound characteristics to high-level structural information about content collections. MPEG-7 is also unique in its tools for structuring information about content.

MPEG-7 will complement MPEG-4, not replace it. **MPEG-4 defines how to represent content; MPEG-7 specifies how to describe it**. MPEG-7 and MPEG-4 form a great couple, especially when MPEG-4 objects are used. With MPEG-7, it is now possible to exchange information about multimedia content in interoperable ways, making it easier to find content and identify just what you wanted to use. This could be an extremely powerful set of tools for us in CCTV where weeks and months of information can be recorded on a set of hard drives. MPEG-7 could provide the answers about how to find a particular object, a guy in the red shirt, for example, or a blue car that was stolen in the street. MPEG-7 information will be, without any doubt, added to broadcasts, DVR recording, and various visual search engines. It will greatly facilitate managing multimedia content in large storage drives.

Although currently in CCTV some products (DVRs) have the intelligence to find objects in certain areas of activity (or inactivity), with the MPEG-7 such a search will be much more flexible and more powerful, making CCTV even more efficient. We are yet to see when this will be implemented.

MPEG-21

MPEG-21 is also a new standard, and it is not used in CCTV yet, but, in order to be complete with this section we should mention it.

The MPEG-21 goal is to describe a "big picture" of how different elements to build an infrastructure for the delivery and consumption of multimedia content – existing or under development – relate to each other. The MPEG-21 world consists of Users that interact with Digital Items. A Digital Item can be anything from an elemental piece of content (a single picture, a sound track) to a complete collection of audiovisual works. A User can be anyone who deals with a Digital Item, from producers to vendors to end-users. Interestingly, all Users are "equal" in MPEG-21, in the sense that they all have their rights and interests in Digital Items, and they all need to be able to express those. For example, usage information is valuable content in itself; an end-user will want control over its utilization. A driving force behind MPEG-21 is the notion that the digital revolution gives every consumer the chance to play new roles in the multimedia food chain.

H.320

The H.320 standard is an ITU-T recommendation. It consists of a series of substandards that deal with individual aspects of a complete system. For example, H.261 describes video coding, and H.221 is responsible for multiplexing audio, video, data, and control information.

The H.320 recommendation is intended mainly for video conferencing systems and videophones and is optimized for transmission via ISDN (Integrated Services Digital Network). At 128 kb/s (2 × ISDN B channels), it is possible to achieve good image quality with a very good image refresh rate. Because of its large range of bandwidth from 64 to 1920 kb/s, it can be used via almost all communications media (LAN, WAN). In particular, because H.320 was developed for two-way video communication between human beings, **this standard is optimized for real-time transmission and does not have the latency typical for MPEG-1 and MPEG-2**.

In person-to-person communication, it is important that delays remain below 100 to 200 ms because otherwise natural conversation is difficult. This short latency is very useful for CCTV, especially when PTZ cameras are remotely controlled. In fact, some DVR manufacturers that use other image compressions for recording camera images use one of the H.320 standards when switching to PTZ control.

An important feature that can be implemented with H.320 in compliance with the standard is influencing the image quality. The user can choose between resolution-optimized or motion-optimized transmission and set a suitable compromise.

H.320 is not limited to image coding; it also standardizes all other components of a complete transmission system. The great advantage of H.320 therefore lies in its compatibility between terminals of different manufacturers. For example, an ISDN videophone from one manufacturer can communicate audiovisually with an ISDN video conferencing system or an ISDN video transmitter of another manufacturer if both support the H.320 standard.

H.261

The H.261 is one of the oldest video compression standards and is the actual standard some DVR manufacturers started using in CCTV in the very beginning of the new DVR revolution. **The H.261 is the actual video compression part of the H.320 video conferencing standard**. At the time when H.261 was introduced (the beginning of the 1980s) there was no Internet, and the fastest digital method of transmission was done over ISDN lines (Integrated Services Digital Networks). That means that it was optimized to compress video for transmission over ISDN lines that provide a range of bandwidths from 64 kb/s to about 1.5 Mb/s. Like the MPEG standards, H.261 specifies formats appropriate for both storage and transmission of compressed video. Moreover, since bandwidth over ISDN is available in increments of 64 kb/s, the H.261 standard permits the compression options to be adjusted in a manner that increases required bandwidth in 64 kb/s increments to get higher video quality.

H.261 normally works with images in CIF (Common Interchange Format) resolution (352 × 288 for PAL and 352 × 240 for NTSC), which was in actual fact invented as a format exactly with the intro-

duction of H.261. A quarter of this resolution was also introduced and it is widely known as ***Quarter CIF***, or QCIF (176 × 144). Although the actual H.261 standard in one of its documents describes a high-resolution mode with 704 × 576 pixels, the majority of DVRs using H.261 use CIF size images, comparable to VHS, as was the case with MPEG-1. Although video can be scaled to larger sizes on PC screens, the lower the resolution of the actual transmitted image, the more blocky and pixelated the viewed image becomes.

H.261 has seen its greatest application in the deployment of a variety of H.320 compliant video conferencing systems. H.261 compression is not really that impressive for higher quality video in CCTV, but it was most useful for remote connectivity over narrow bandwidths. I use the past tense “was” here rather than “is” because MPEG-4 has definitely overtaken the H.261 in quality for the same narrow bandwidth.

H.263

The H.263 standard was approved around 1996 and evolved from H.261, being a further development of H.261. **H.263 has been optimized specially for low data transfer rates below 64 kb/s within the H.320 standard**, for example, for connections via modem and analog telephone lines. H.263 is an alternative to H.261 if both ends support this standard. Especially for transmission in the mobile radio network GSM (9600 bit/s) or in the analog telephone network, use of H.263 improves the image quality and image refresh rate. At higher data rates the quality is comparable to H.261.

By incorporating a more efficient video-compression algorithm, the H.263 standard offers higher video quality than H.261 at every level of bandwidth, including ISDN. H.263 allows video to be transmitted at the very low bit rates required by modems in the range of 15 to 20 kb/s. The original intent was to enable video calls and video conferencing over conventional telephone lines. Although QCIF may support these applications, a new image resolution, ***Sub-QCIF***, was added to ensure this capability. Moreover, higher resolutions were added to exploit capabilities made possible by newer transmission and compression technologies. Sub-QCIF (SQCIF) permits video as small as 128 horizontal pixels by 96 vertical pixels to be transmitted. The other two additions support image resolutions that are four times and sixteen times the size of the CIF image (some people refer to it as 4CIF) – 704 horizontal × 576 vertical pixels and 1408 horizontal × 1152 vertical pixels, respectively. Of these, H.263 equipment must support only the SQCIF, the QCIF, and the CIF formats. All others are optional.

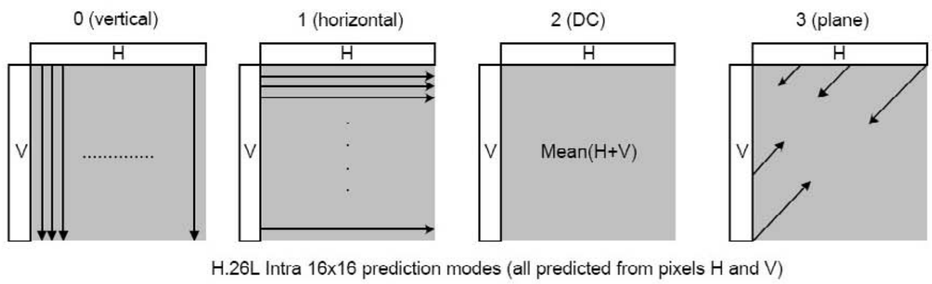
H.264

The H.264 seems to be the most promising new standard development. It is produced by the ITU-T ***Video Coding Experts Group*** (VCEG) together with the ISO’s MPEG. This historical and collective effort is also known as the Joint Video Team (JVT). This standard is identical to ISO MPEG-4 part 10, also known as AVC, for ***Advanced Video Coding***. The final drafting work on the standard was completed in May 2003. This standard merges the know-how used in H.263 and MPEG-4.

H.264 is a name related to the ITU-T line of H.26x video standards, whereas AVC relates to its ISO MPEG roots. Some people call the standard H.264/AVC, or AVC/H.264, to emphasize the common

heritage. The name H.26L, also related to its ITU-T history, is far less common but is still used.

The intent of H.264 project was to create a standard that would lead to fast implementations, using low bit rates, that is, implementations that would demand little from the decoder hardware and from the network bandwidth. **H.264 contains several new features that allow it to compress video much more effectively than older codecs**. There is a new ***Context-Adaptive Binary Arithmetic Coding*** (CABAC) used in H.264 to losslessly compress syntax elements in the video stream. H.264 also implements an in-loop de-blocking filter that helps **prevent the ringing and blocking artifacts** common to other DCT-based image compression techniques. In previous video standards, motion compensation is handled by allowing blocks in a frame to refer only to the frame before it. H.264 allows frames to be predicted from other frames that are arbitrarily far in the past. This usually allows modest improvements in bit rate and quality in most scenes. But, for example, in certain types of scenes with rapid repetitive flashing, it allows a massive reduction in bit rate. These ideas, along with many other new ideas, help H.264 to perform significantly better than MPEG-4 ASP can. **H.264 can usually perform radically better than MPEG-2 at a fraction of the bit rate.** Various tests and comparisons have shown that H.264 offers at least two to three times better efficiency than MPEG-2 for the same picture quality.



H.264 uses sophisticated prediction of macroblocks.

In addition, the JVT is nearing completion of the development of some extensions to the original standard that are known as the Fidelity Range Extensions. These extensions will support higher-fidelity video coding by supporting increased sample accuracy (including 10-bit and 12-bit coding) and higher-resolution color information (including sampling structures known as YUV 4:2:2 and YUV 4:4:4).

H.264 is already widely used for video conferencing. It has also been preliminarily **adopted as a mandatory part of the future DVD specification known as HD-DVD**, developed by the DVD Forum.

Like many ISO video standards, H.264 has a reference implementation that can be freely downloaded. Its main concern is to give examples of H.264 features instead of being a useful application per se.

One leader in video editing and multimedia projects, Apple Computer, has already integrated the H.264 into “Tiger,” the new version of Mac OS X. Others will no doubt follow.



Courtesy of Toshiba

HD DVDs of 30 GB just starting to appear

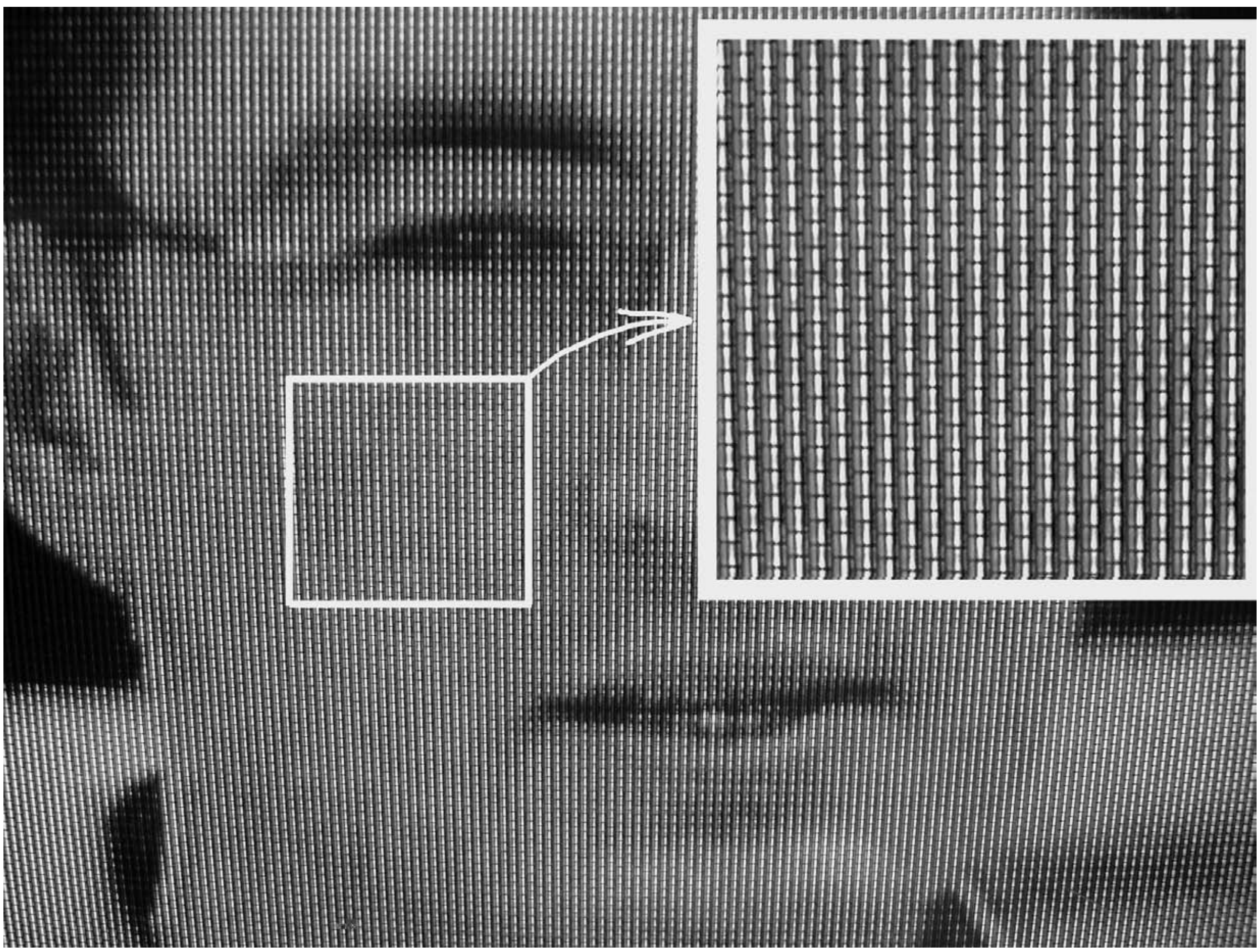
About pixels and resolution

All of the compressions discussed previously are composed of one smallest element . This is the "building block" of any digital still image or video – the pixel. It is important to analyze the pixel closer, for this defines the clarity of an image and how much we can see.

Pixel is short for *Picture Elements*, sometimes also referred to as *pels*. These are the smallest elements of any electronic (digitized) picture. Pixels are the atoms of an image. Understanding pixels is especially important in the digital photography, but the same could be said for us in CCTV, especially with the introduction of the digital video recorder. Pixel terminology is also used when printing leaflets or catalogues, and also when using computer LCD screens, and yet they may not necessarily have the same meaning as in digitized video.

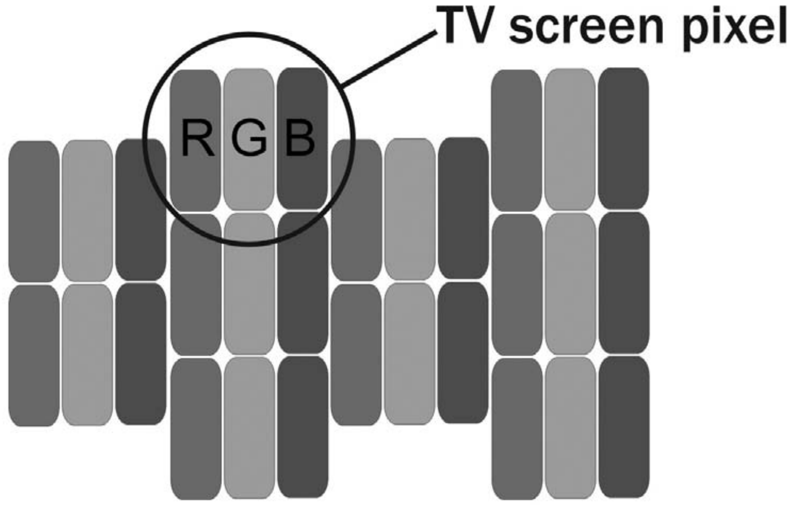
Pixels can be associated with the image resolution, but understanding the differences between various kinds of pixels is very important, since often we try to recognize a small detail (such as intruder face) of a highly compressed image.

In the offset printing industry, the picture elements are usually referred to not as pixels, but as



RGB phosphor grill mask on a color CRT and smallest picture elements on a monitor

dots; they have the same meaning, however, one cannot dissect it any more and get additional, meaningful information about the image, of which that pixel is part of. So, in very simple terms, pixels contain elementary information about the smallest details of a picture, which is the information about the pixel's color and the brightness of that color. In television terms, we refer to these attributes as chrominance and luminance of the picture element. Because of the need to represent a variety of colors and shades with only a limited number of primary colors, pixels are composed of smaller details, each representing a certain value of their primary color. So, in fact, pixels are not really the smallest elements of a picture, but only as a group of all the primary elements they do represent a "complete" pixel.

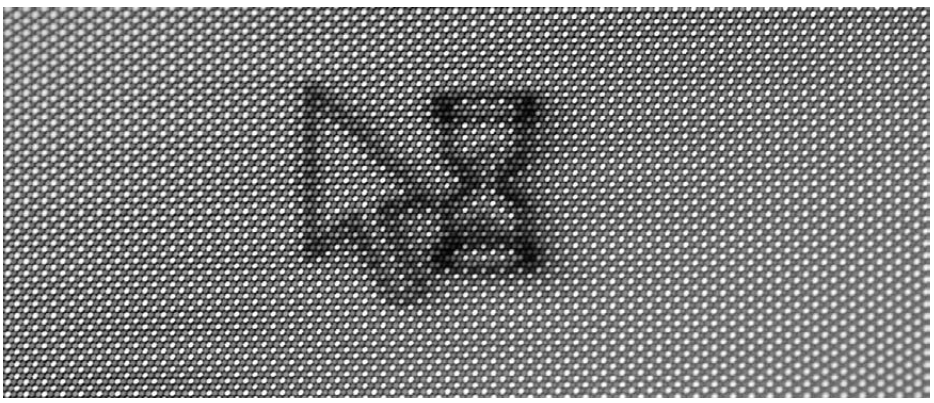


RGB grill mask on a color CRT. Note the half height vertical displacement for use with interlaced scanning.

A very important question is: Are the pixels used in digital photography, television, and printing of the same kind? The answer is – No, they are not. The differences between various pixels are the source of many misunderstandings and misinterpretations in many imaging industries and applications, one of which is CCTV.

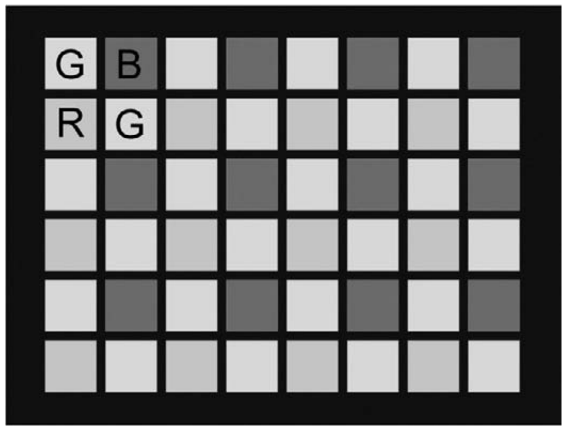
In CCTV, as all of you would know, we use red, green, and blue phosphor colors to "simulate" other colors. With the three primary colors (RGB) (these are the primary colors in television), we can represent almost any other color we can see with our eyes. With the appropriate luminance intensity of the R, G, and B phosphor we can also represent the variety of brightness pixels have (from black to white) including skin colors. The actual color mixing occurs in our eyes when viewing the pixels from a typical viewing distance, which is usually so large relative to the pixel size that we perceive the three elementary dots as one resultant – color dot, which has the new color – the result of the additive mixing of the red, green, and blue phosphor in the TV screen pixels.

In analog television, which the majority of us still use (and, of course, it is also used in CCTV), pixels as elementary detail do exist at both ends of the image chain – at the input (i.e., camera end) and at the output (i.e., monitor end). At the camera end, we use CCD chips, where the smallest elements



RGB elements on a Delta CRT are different.

– pixels, are usually made up of red, green, and blue components. These color pixel components respond to the red, green, and blue portion of the spectrum of the projected image, thus producing electrons proportional to the color component of that picture element projected at that physical location. In the 3 CCD chip cameras the light is split into three color groups: red, green, and blue spectral response. This split is done with a split prism, and each of the three color groups is then projected onto its own CCD chip. This means there are three CCD chips, one for each of the primary colors. Clearly, in cameras with 3 CCD chips we have a high-quality video signal, in terms of both resolution and color reproduction. Unfortunately, in CCTV, we rarely use 3 CCD chip cameras because they are much more expensive and are usually bulkier. What we do use most often is single-chip color cameras. So, in a single-chip color CCD camera each pixel is actually the collection of the red, green, and blue primary color elements at that location. It is fair to say that there are CCD chips where primary colors are not red, green, and blue, but rather cyan, yellow, and magenta (similar to the printing primary colors), but such CCD chips are in use far less in CCTV, and we will not consider them as an important component of a CCTV system. If we did, however, we would need to know that the cyan, magenta, and yellow components are converted to red, green, and blue values using a lookup table inside the camera, since the composite video signal generated at the end of the camera electronics still needs to be represented with RGB values. As can be seen from the simplified illustration of the single CCD chips above, the filtering of RGB colors is in the form of a mosaic, and as a result is called a mosaic filter. It should be noted that there are more green sensors than blue and red (twice as much). This is because the majority of the luminance information is contained within the green spectrum and the human eye is most sensitive to the green color. These green cells are the ones that influence greatly the resolution of the camera.



The RGB CCD chip mosaic filter

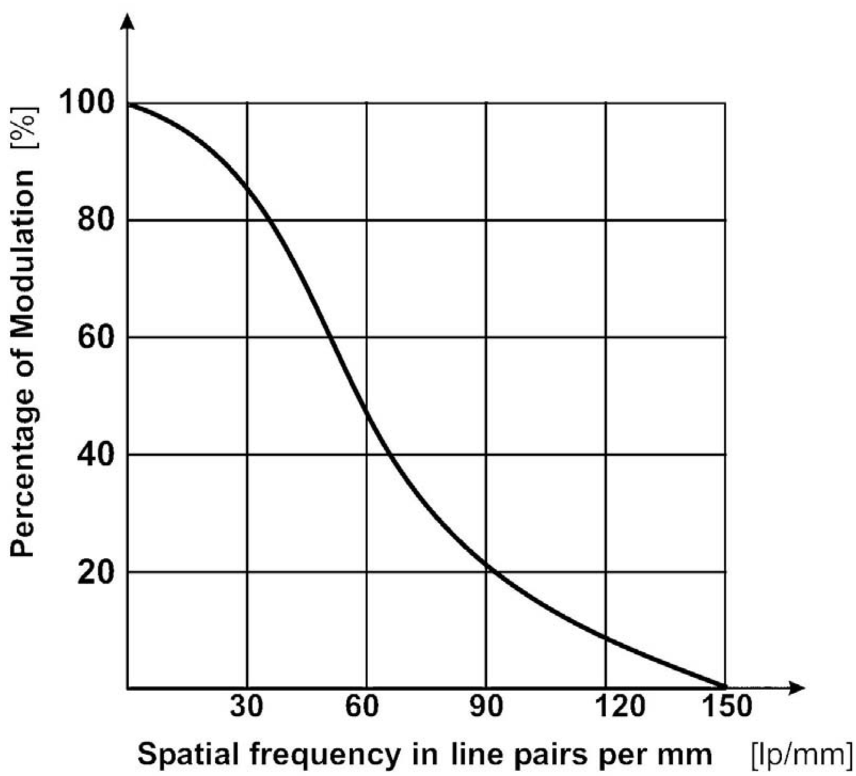
Although it might be logical to assume that the resolution of a single-chip color CCD camera should be obtained by dividing the number of horizontal (three-color) pixels with 3/4 (for the aspect ratio) in order to get the resolution in TV lines, in CCTV practice this is not the case. Because of the mosaic composition on single-chip color cameras, and because of the way an interlaced scanning image is obtained in television, the real single-color CCD chip resolution is approximately 70 – 80% of what the pixel count is. So, for example, a 768 × 582 pixels CCD chip will produce approximately 768/4 × 3 × 0.8 = 460 TV lines. Three CCD chips color cameras have an advantage of at least 100 TV lines extra simply because they do not use such a mosaic, but rather all pixels of all three colors are used.

Also, an important digression would be to remind the readers that in the days before the CCD chip cameras (when tubes were used) because of the way a video image was read off the tube face plate (scanning with a continuous electron beam), we did not have a discrete and finite smallest picture element (as in CCDs). Discrete picture elements were introduced with color television, when TV sets were made with CRTs with color grill. It was this color grill that split the beam into red, green, and blue dots.

When using monochrome tube cameras we did not talk about pixels, but rather resolution – which was directly dependent on the smallest electron beam that can be produced by the camera and reproduced on the monochrome TV screen. If you recall, monochrome monitors had quite a high resolution, simply because there was no physical limitation with any kind of mechanical grill, or mesh, as introduced later in the color television development. It was purely up to the electron beam precision (and the electronics driving it) to reproduce the details captured by the electron beam at the camera end. So, coming to current CCTV technology, we need to understand that the resolution of an image is defined primarily by the source, that is, CCD camera resolution, which is dependent on the number of pixels such a CCD chip has.

We cannot show more details on a monitor (even if the monitor could display more) than what the actual CCD chip has captured. Although we can always state the number of pixels a CCD chip has, we still use the term of TV lines as qualification of the quality of details we get from a camera. The resolution in TV lines is measured with test charts and in the real world there could never be a perfect alignment of a test chart pattern relative to the projected image on the CCD chip. As a result, TV lines are showing less detail than the CCD pixel count would indicate. When a video signal is reproduced on a monitor screen, the smallest picture element is clearly defined by the smallest of the two – camera CCD pixels or monitor pixels. If we have a very low-resolution monitor – for example, a small, 23 cm CRT with 330 TV lines specification – and our camera produces a high-resolution 480 TV lines signal, we can only see what the monitor shows – 330 TV lines. If we have, for example, a high-definition TV monitor capable of showing over 700 TV lines, and we put our 480 TV lines camera signal through, we can only see what the camera resolution shows.

In order to get a complete picture of the resolution measurements, it is also important to mention that lens resolving power, or quality, is measured in ***lines per millimeter*** (***l/mm***) (please refer to Chapetr 3). There are optical specification charts that show such function of the resolving power in ***l/mm*** versus the contrast produced by the lens. This is usually referred to as ***Modulation Transfer Function*** (MTF). Here things are getting more complicated because MTF counts only the black lines on a white background (as opposed to counting both black and white lines to express the resolution in TV lines, as we do in CCTV).

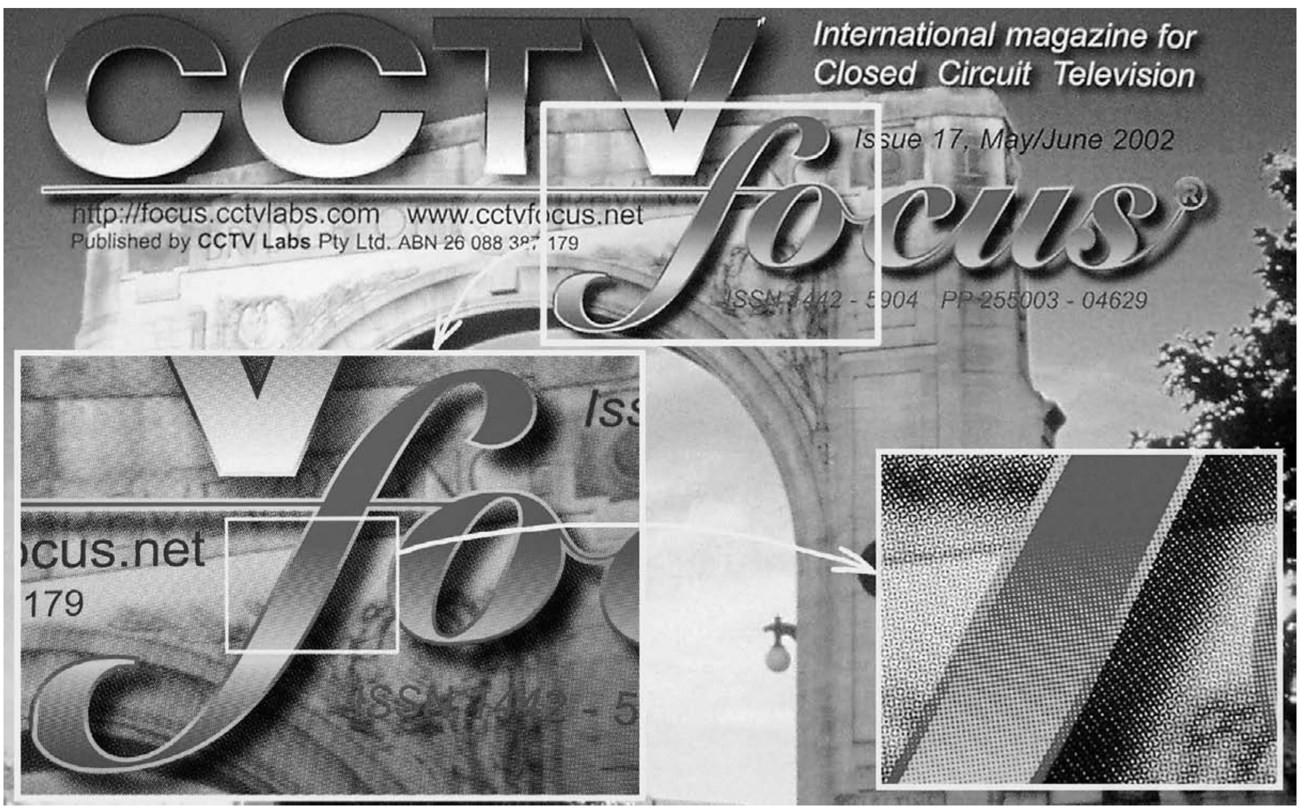


Lens resolution expressed in line pairs per millimeter

Dots per inch (DPI)

The ***term dots per inch*** (DPI) is commonly used today, but because of the different definition of the term ***dot*** it is a source of confusion and misinterpretation (somewhat similar to what we have when we discuss TV lines and lines in defining a CCTV resolution). In the printing technology we express resolution in dots per inch (DPI). Certainly, by knowing that 1" is equal to 25.4 mm, the printing resolution can also be expressed in dots per millimeter, but this is not common. So when we say 300 DPI resolution, this practically means more than 10 dots per millimeter. This is certainly a very tiny dimension, and the human eye cannot distinguish two different tiny color dots when they are very close to each other in a 300 DPI print. In order to make a comparison, it is possible to convert the CCTV screen resolution in dots per inch.

But here is one big but. The mixing of colors in the printing industry is done in a completely different way – by subtractive mixing of other than RGB primary colors – cyan, magenta, and yellow. Black is added for additional dark tones, although theoretically, CMY are sufficient to produce other colors. All of you know that we call this CMYK printing, where CMYK color space is used. So basically, we use four different inks when printing color magazines or books, and in order to produce the resultant color the smallest picture elements in the printing industry are produced by having all these elementary color dots very close to each other (similarly to the TV screen mixing). The difference compared to TV monitors is that the colors are not positioned next to each other in line (which is typically the case with most LCD and CRT phosphor these days), but rather the four color dots screening are positioned



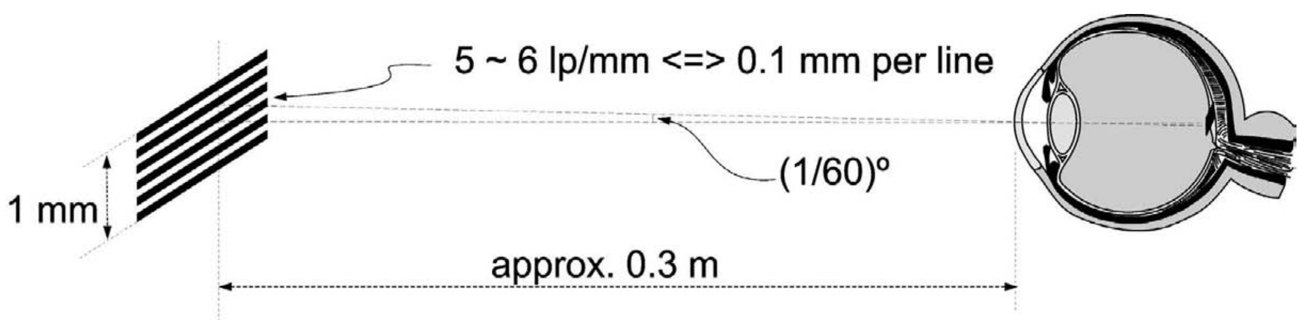
Unfortunately, we cannot show CMYK offset printing example here, but the enlarged section (bottom right) should show the CMYK pixel pattern typical for offset printing.

at various angles, such as 45º for black, 75º for magenta, 90º for yellow, and 105º for cyan (see the illustration, although, unfortunately, we could not reproduce it in color for this book). In order to have high-quality print magazines or brochures, the printing industry requires 300 DPI resolution. So when we read a magazine from a normal reading distance (typically 0.5 m), the color pixels cannot be detected by a normal eye and we only see the resultant (subtractive) color mix.

Psychophysiology of viewing details

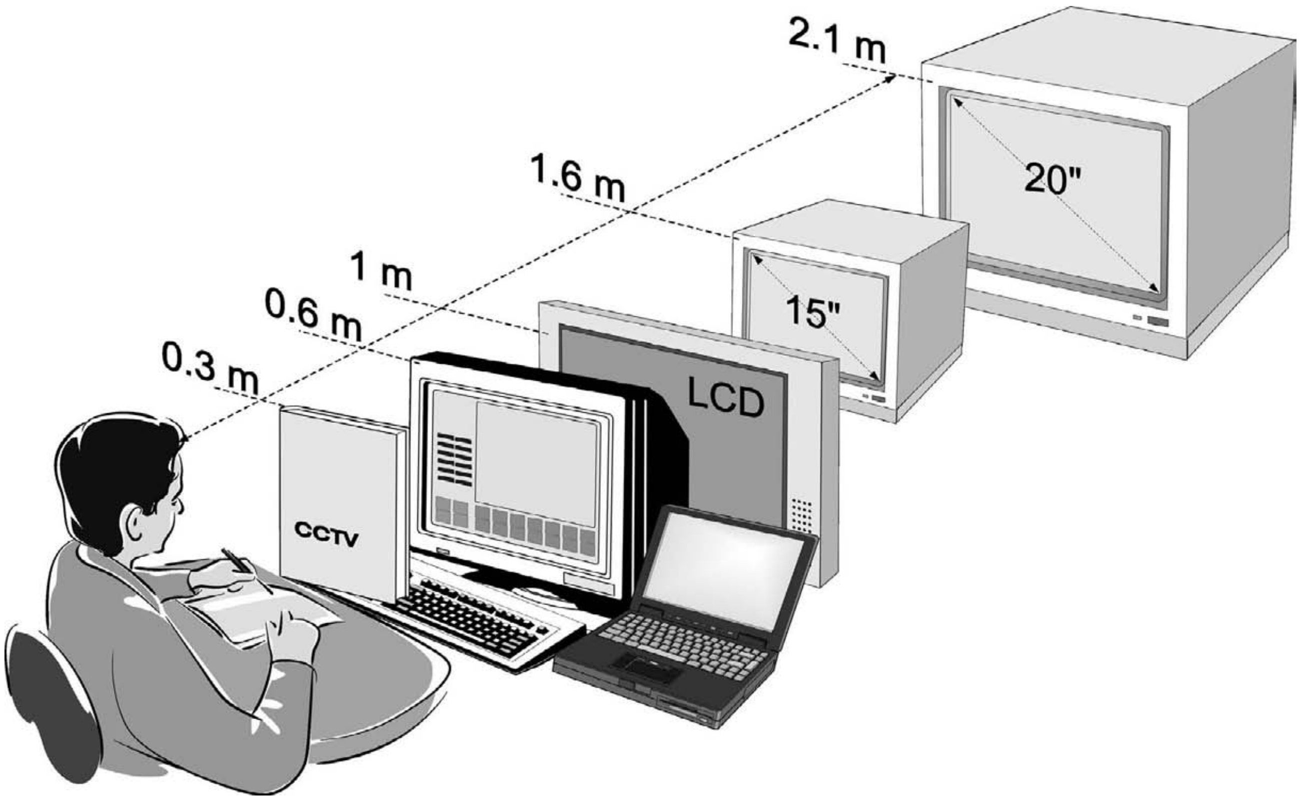
Through experiments and testing it has been found that **the most a human eye can resolve is not more than 5 to 6 lp/mm** (line pairs per millimeter). This refers to an optimum distance between eye and object of around 0.3 m, as when you are reading a fine text. This equates to a minimum angle of about one-sixtieth of a degree (1/60°). So, **1/60º is considered the limit of angular discrimination for normal vision**. We can use this minimum angular vision for better understanding and optimizing the psychophysiology of the viewing.

A known viewing distance parameter from Chapter 6 recommends for CCTV a **viewing distance of around seven times the monitor height**. So it is important to understand that viewing distance is an important factor for the psychophysiological experience of seeing details in an image. It is of no use if a viewer gets closer to the monitor, but it is also not going to get any better if he is positioned farther away from the monitor screen. For the analog PAL, with 576 active lines, the corresponding optimum details viewing distance is obtained from the 5 to 6 lp/mm, projected at the distance where the monitor screen is. So, for example, if we use the 7 × picture height rule, for a 15" (38 cm) CCTV monitor, whose picture height would be around 23 cm, the recommended viewing distance is 483 picture lines of 525-line television, and the corresponding viewing distance is about seven times picture height, which is around 1.6 m. The maximum resolving power of the human eye at that distance is simply a factor of 5 from what is shown in the graphics below (because 0.3 m goes around six times in 1.6 m). This equates to around 1 lp/mm (line pairs per millimeter), or 0.5 lines/mm, which is roughly what the 576 active lines will occupy on the screen. This assumes a high-quality, high-resolution monitor of course. Coming much closer to such a monitor will not show any more details, nor will going further away be of any advantage. Coming closer to a CCTV monitor has the same effect as when a much larger monitor is put in place. If you decide, for example, to put a 21" color monitor at the same distance of 1.6 m instead of the 23" monitor, the picture clarity and video details will appear much worse to the viewer. The optimum resolution distance for a 21" CCTV monitor would be 2.1 m.



The human eye acuity angle is 1/60º.

Similar logic and calculation will show that viewing a high-resolution computer screen such as a CRT with dot pitch of 0.21 mm is optimum at a distance of around 0.6 m. The majority of LCD monitors do not have such a fine pixel detail, but typically around 0.28 mm, so they actually will look slightly better if viewed from around 1 m distance.



The optimum distances for maximum eye resolution, based on 1/60° acuity

A much better looking picture would be shown on a computer screen (viewed from the same distance), where a typical XGA monitor of 1024 × 768 pixels has an actual equivalent resolution of 92 DPI. To see how this was obtained, divide 1024 pixels with the width of a 14" LCD notebook screen. Computer screens therefore have a larger area (pixel count) but also a higher frame rate than we use in CCTV. Please note that in order to display such a high-quality image on the screen, the computer has to have a high quality video card with sufficient memory capable of processing that number of pixels (1024 × 768) with the number of colors sufficient to replicate a live scene (24-bit color, equivalent to 16.7 millions of combinations of the RGB). And another important note: such a display neither complies with PAL nor with NTSC analog standard, but it is a computer XGA graphic display.

Printed material has even better resolution per mm than any kind of monitor. This is why you sometimes may see better details when a video image is printed out on a high-quality ink jet photo paper than looking at the same image on a CCTV monitor. We can express monitor resolution in DPI, but it would not make the same sense as in printing. This is primarily because when viewing a monitor screen we (usually) do not stand as close as when reading this book. So, let us assume we do have a very high-resolution CCTV camera image displayed on a very high-quality CCTV monitor, which would be quoted as having 500 TV horizontal lines of resolution. If the monitor has, for example, 38 cm (15") diagonal

screen size, the 500 TVL resolution image means 666 vertical lines across the 30 cm screen width (30 cm = 11.8"). The 666 lines divided by the 11.8" gives 56 DPI! This resolution is close to the highest we can get when displaying analog video signal, and it is defined by the video standard (PAL/NTSC).

In order to print a ITU-601 TV frame on an ink jet printer, we need to understand this technology, too, so that we can optimize the printout quality. It is logical to expect that print size and resolution quality can easily be calculated, since we know, for example, that our ink jet printer has, for example, 1440 DPI. This is not so, however. The dots per inch as described in the specification on your fine ink jet printer (like 720 DPI, or 1440 DPI) refer to the finest dots that can be produced by each of the cyan, magenta, yellow, or black ink nozzles of the ink head. Adding to the confusion is the fact that this is not the same as the DPI described for magazine and book printing. The actual “natural” colors of the ink jet printouts are obtained by a dithering process, which is actually spraying and mixing the ink jet dots with various sizes and combining them to produce a resultant color. In essence, the ink jet color printers are binary devices in which the cyan, magenta, yellow, and black dots are either “on” (printed) or “off” (not printed), with no intermediate levels possible. This is conceptually different from the RGB phosphor on a CRT, where each phosphor can have a variety of intensity. A “binary” CMYK printer can only print five “solid” colors (cyan, magenta, yellow, black, and white). White is actually the nonprinted paper background color, but that is also used. Clearly, this is not a big enough palette to deliver good color print quality, which is where **half toning** comes in. This is still the case even with the new photo quality ink jet printers that have additional two colors: light-cyan and light-magenta (for better human flash reproduction). Half toning algorithms divide a printer’s native dot resolution into a grid of halftone cells and then turn on varying numbers of dots within these cells in order to mimic a variable dot size. By carefully combining cells containing different proportions of CMYK dots, a half toning printer can “fool” the human eye into seeing a palette of millions of colors rather than just a few.

A simple rule of thumb by some imaging people, such as Adobe, is to divide the ink jet DPI as specified by the ink jet printer manufacturers with 4 to get the “real” color dots per inch. Practically, this means that a 720 ink jet DPI printer can reproduce 180 color dots per inch. To achieve highest quality, it is important to use high-quality printing paper. For best results, inks and photo paper of the corresponding printer manufacturer are recommended.

An important conclusion to make here is that when a digitized and compressed image is exported and given as evidence to a third party (police, for example) it is desirable to have it in the original format, or at least exported to BMP so that no additional compression artifacts are introduced. If you are comparing various image compressions, the most objective way of comparing them is that either when the image is printed out on the same high-quality photo paper, or when they are compared on a computer screen, both should be exported in a noncompressed BMP format.



High-quality color printers these days are cheap and should be a standard part of a CCTV system.

Recognizing faces and license plates in CCTV

In CCTV, one of the most important functions is to be able to recognize a person, an intruder, or a group of people involved in an accident, for example.

Second on the list of most required functions is recognizing a vehicle's license plate. Certainly, CCTV cameras and digital recorders have other applications, that are not always related to security or surveillance, but since the two mentioned are the most common ones, we will explain the requirements in designing and setting up the system that will guarantee successful identification of faces and license plates.

Our main problem is the limited number of pixels both in the CCTV cameras and in the ITU-601 digitization recommendation, which, as mentioned in the beginning of this chapter, is around 400,000 pixels. So, most of the time the "trick" is to find a suitable lens and position for the camera so that it can see sufficient details for identifying people or license plates. Customers are usually the ones who expect one camera to cover everything, see everything, and recognize everything. This topic has been discussed often, and it still is a stumbling block in designing various projects. If we all work under the pressure of a budget (and the budget is a very important consideration) the tendency is to have as small number of cameras as possible. Yet, when there is an incident and a positive identification is required, the CCTV system designer could be blamed for having a system that cannot recognize a face or a car, even if they are captured in the camera field of view. Here is a simple advise: **do not compromise your system design**; rather, **educate the customers** so that they understand why more cameras with certain coverage would be required. If necessary, have two cameras covering a foyer entrance, for example, one having a wide and global coverage, the other with a narrower angle of view picking up faces entering the foyer. Initially, this might seem to be an overkill, but when a suspected intruder is identified and captured, the system proves its existence. This **is** the purpose of a surveillance system.

Finding a camera lens to give you an angle of view for positive identification is not science fiction, and it is already known from the analog part of the CCTV design. Here, we will only highlight the fact that when using digitized video certain image losses will occur and they have to be taken into account.

In actual fact, various national standards written specifically for CCTV define what views are required in order to recognize faces and license plates. These standards are not necessarily identical for all countries, but we will use what is close to the author of this book, and that is the Australian CCTV Standards, which should give you sufficient information for practical use and even perhaps for further refining.

If digital recording is used, it is recommended that a full PAL frame resolution and highest picture quality be used (i.e., 704 × 576 active pixels, which is equivalent to 720 × 576 ITU frame grabbing recommendations). Where possible, for better vertical resolution, TV frames are recommended instead of TV fields recording, although these standard recommendations are good for field recording as well.

If the target is a person and the CCTV system has an installed limiting resolution of at least 400 TV lines (most of them would have around 460 TVL), the recommended minimum sizes of the targets in order to be recognized are:

- For **face identification** the entire target person should represent not less than 100% of screen height. It is assumed that a person's face (head) occupies around 15% of a person's height. If digitized image is used, the head should be not less than 90 pixels high, before a compression is applied.

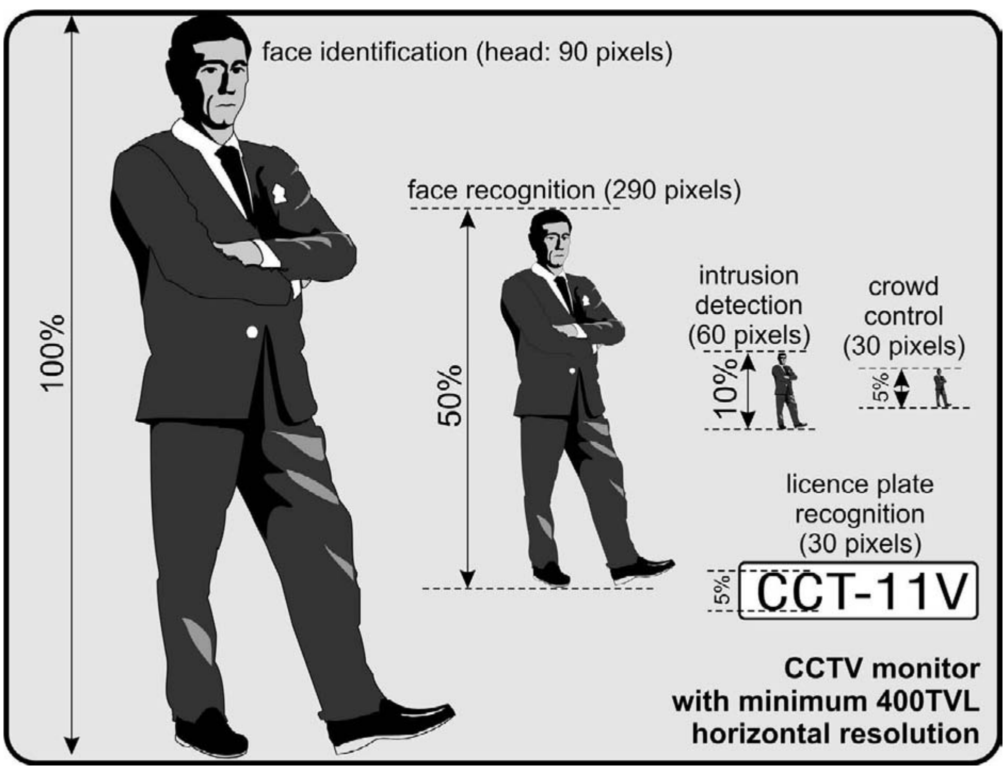
- For **face recognition** the entire target person should represent not less than 50% of picture height. If a digitized image is used, the person's image height should be not less than 288 pixels, before a compression is applied.

- For **detection of an intruder** the entire target person should represent not less than 10% of picture height. If a digitized image is used, the target person should be not less than 60 pixels high, before a compression is applied.

- For **crowd control** (monitoring) the entire target person should represent not less than 5% of picture height. If a digitized image is used the target person should be not less than 30 pixels high, before a compression is applied.

- For **vehicle number plate visual recognition** the license plate characters should be not less than 5% of the monitor height. If a digitized image is used the license plate should be not less than 30 pixels high, before a compression is applied.

The CCTV Labs test chart (***www.cctvlabs.com***) has display indicators that can be used to verify system compliance with all of the details listed above.



Minimum object sizes relative to the monitor display height in order to recognize or identify the objects.

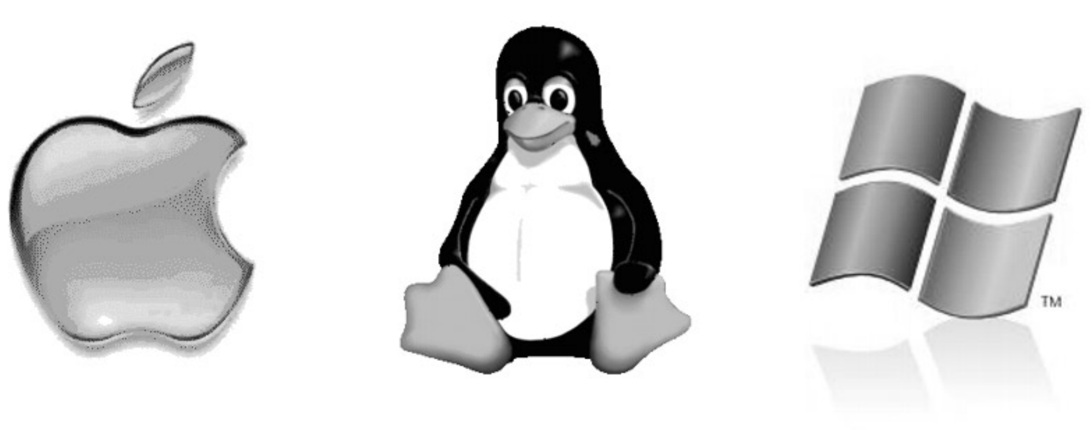
Operating systems and hard disks

In order for a computer to work, it needs appropriate hardware and appropriate software that understands the environment in which it works. When a computer starts up, the first thing that happens is that it loads the BIOS table (***Beginners Instructions Operating Set***), which has all the hardware configuration details, hard disks, video cards, keyboard, mouse, communication ports, parallel ports, and so on. Once the BIOS defines all these details, it goes to a special section of the hard drive called boot record area and looks for an operating system. The ***operating system*** (OS) is software that usually resides on the hard disk, and when it loads, it brings up a graphical user interface (GUI) and connects the whole system in a meaningful interactive environment, loading various drivers, displaying certain quality images, and accepting and executing commands as defined by the computer user or application. **The OS is what the name suggests: it is a system to operate with the computer**, and it is the basis for various applications and specialized programs, such as spreadsheet program, word processing, photo editing, or video editing.

Many DVRs in CCTV fall into this category, since they use one of the few popular OSs and add video processing as specialized application to it. Most common OSs used in CCTV are Windows and Linux. There are other OSs as well, such as Unix, Solaris, and Mac OS X, but none of these is used in CCTV; this is why we will not be going in depth comparing and analyzing them.

Some DVRs do not load their OS from a hard disk, but rather from a chip (usually flash memory or EPROM). Sometimes you may find that DVR manufacturers refer to the OS as a ***Real Time Operating System*** (RTOS) or ***Embedded OS***. Running a DVR with an embedded OS simplifies things, for the OS is then smaller and it is faster to load. Also, if a hard disk fails, there is no need to install the OS from scratch (which would usually be the case if a DVR with an OS on hard disk fails). The one important limitation with DVRs with OS on a chip is that they are not as flexible and easy to upgrade as the ones loaded on a hard disk.

One of the most important requirements in security and surveillance is the stability of the OS. Long-term operation in CCTV is sometimes more demanding than a busy web server, and even more demanding



The trademarks of the three main operating systems: Mac, Linux, and Windows

than a typical office or home computer usage. A web server can go down for a few minutes or maybe even hours for maintenance purposes, but a DVR in security is expected to run without interruption for months and years. This is a big task. The intensity of writing and reading data to and from hard disks is usually higher than web servers, as video data is much larger than handling web pages or e-mails, for example. Not all operating systems and hardware are suitable for such a long and uninterrupted operation. One reason why the majority of web servers on the Internet these days are running on Linux is exactly that – the **long-term stability**. This is not to say that the popular and widely spread Windows is not suitable at all, but readers should be made aware that the current statistic shows that identical hardware with Intel processors (which makes the majority of PCs) will perform faster and more reliably with Linux than with Windows.

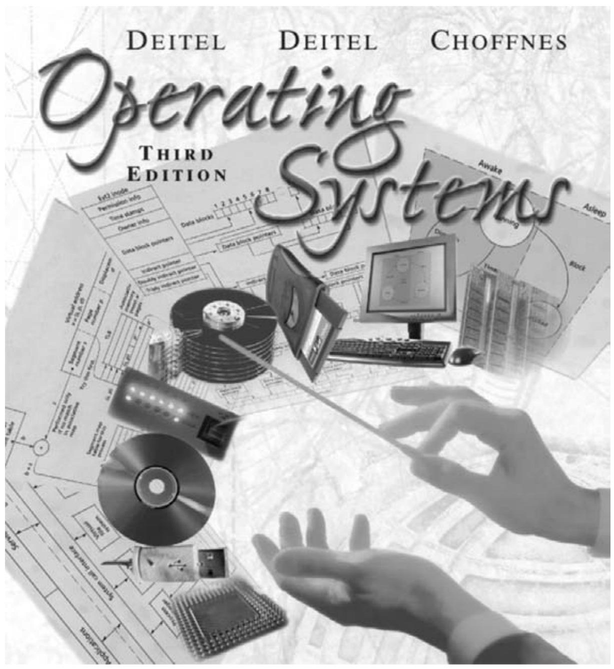
Linux is still a young operating system written by a Finnish student by the name of Linus Torvald, and it is based on Unix, one of the oldest and most robust industry standards, which is (unfortunately) licensed. Linux has picked up so much in only 10 years of its existence because of its concept that the source code for **Linux is freely available to everyone** (developed under GNU – ***General Public License***). When the first version of Linux was written and made freely available to everyone, the author's only requirement was to have any additional improvement or driver written by others to be made available to everyone.

Thousands of software developers, students, and enthusiasts wholeheartedly accepted this idea of free and open source OS.This is why Linux not only became more popular, but also, with more hardware drivers it offered more applications and was continually getting better. Stability is only an inherent part of the Unix concept, but it is further developed and improved with new kernels and file systems. Linux comes in many "flavors" called distributions, but all use the same kernel (the core of the operating system) and have a variety of additions, programs, tools, and GUIs, all of which are license free.

So, when Linux is used in a DVR in CCTV, it has not only a cost benefit, but, maybe more importantly, long-term license independence. If a hard disk inside a DVR with Linux fails (and drives can fail regardless of the OS), installing a new version does not require that any fees or license numbers be entered when re-installing. This is not the case when Windows is used.

Some DVR manufacturers use certain versions of Windows and have gone an extra step forward by having their own software engineers "tweak" the Windows engine to suit their hardware better than when it comes from Microsoft themselves, hence achieving higher stability and reliability.

Others will argue that embedded OSs are an even better choice since there are no issues; if hard disk fails there, the OS is in the flash memory. So, in case

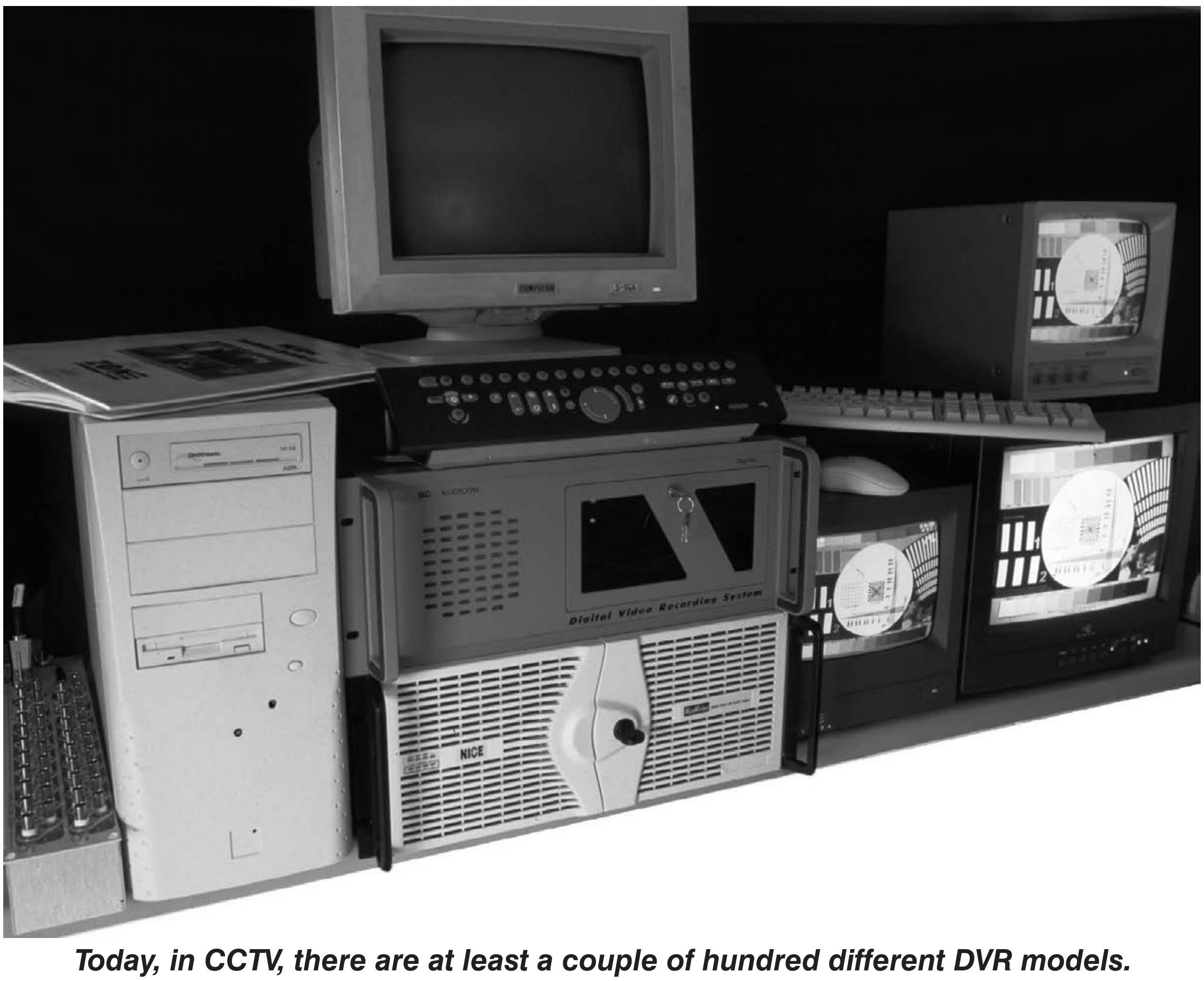


Further reading about various OS's

of a failure, or power loss, a DVR with embedded OS just quickly re-starts and continues recording. There is no need for reloading the OS even if the drive fails; one should just slot in a new one. This might be a better alternative for some. The only limitation here would be the flexibility of having a variety of hardware drivers, the easiness of updating the embedded OS, and the variety of functions one can have. Usually DVRs with full-blown OS, whether Windows or Linux, have many more features and functions since they are not limited in size as is the flash memory. Embedded OS in a flash memory usually has stripped-down functionality.

Today a typical "fully loaded" PC, with many various applications, would use anything between 2 and 5 gigabytes (GB) of hard disk space. This would typically include the operating system (usually Microsoft Windows) and the various applications such as text editors, spreadsheet programs, web browsers, and image editors. User data, created using the applications, can vary significantly, depending on whether you are working with text files only, or text and images, or perhaps, video clips.

Digital video recorders (DVRs) used in CCTV are an exception to this typical scenario. They are designed and intended to use the maximum hard disk space available. With a typical large size hard disk available these days of 300 GB, the internal DVR hard drive capacity can get extended to over 1



Today, in CCTV, there are at least a couple of hundred different DVR models.

TB using up to four such drives. Some larger systems may even include external SCSI or RAID storage drives. A typical DVR, as used in CCTV, would be working really hard, day and night, 24 hours a day, 7 days a week without (ideally) being shut down. DVRs are without any doubt a symbiosis of software and hard disk technology. If any of the two fails, you will have a failed DVR and loss of important recordings.

The need for a better understanding of hard disks and their limitations is greater than ever, especially for those in CCTV. **Even the most stable OS depends on the hardware reliability**. If the hardware fails, the OS can no longer run, even if, technically, the OS has not failed. **The most vulnerable hardware parts of any computer are the moving parts, notably the cooling fans and the spinning hard disks**. These parts most commonly fail simply because of wear and tear, increased temperature, dust, moisture, and mechanical shocks. Some of these issues are addressed by only a few high-end DVR manufacturers. The fact is, at the time of writing this book the majority of DVR manufacturers do not even consider these issues. Driven by the competitive market, very few would go the extra length of putting higher quality hardware and protecting it in its design and production stage. Everything is left in the hands of suppliers and installers and how they educate customers about the importance of the environment, having clean and air-conditioned equipment rooms, and maintaining and monitoring them.

The hard disk drives are the most important DVR hardware that has moving parts (spinning disks), especially because they are the storage area. For this reason, we will devote a bit more space to them later on in this chapter.

It is beyond the scope of this book to analyze all of the intricacies of the various OS available on DVRs today, but we will say a few words about the variety of files and filing system used for recording various data and video on hard disks.

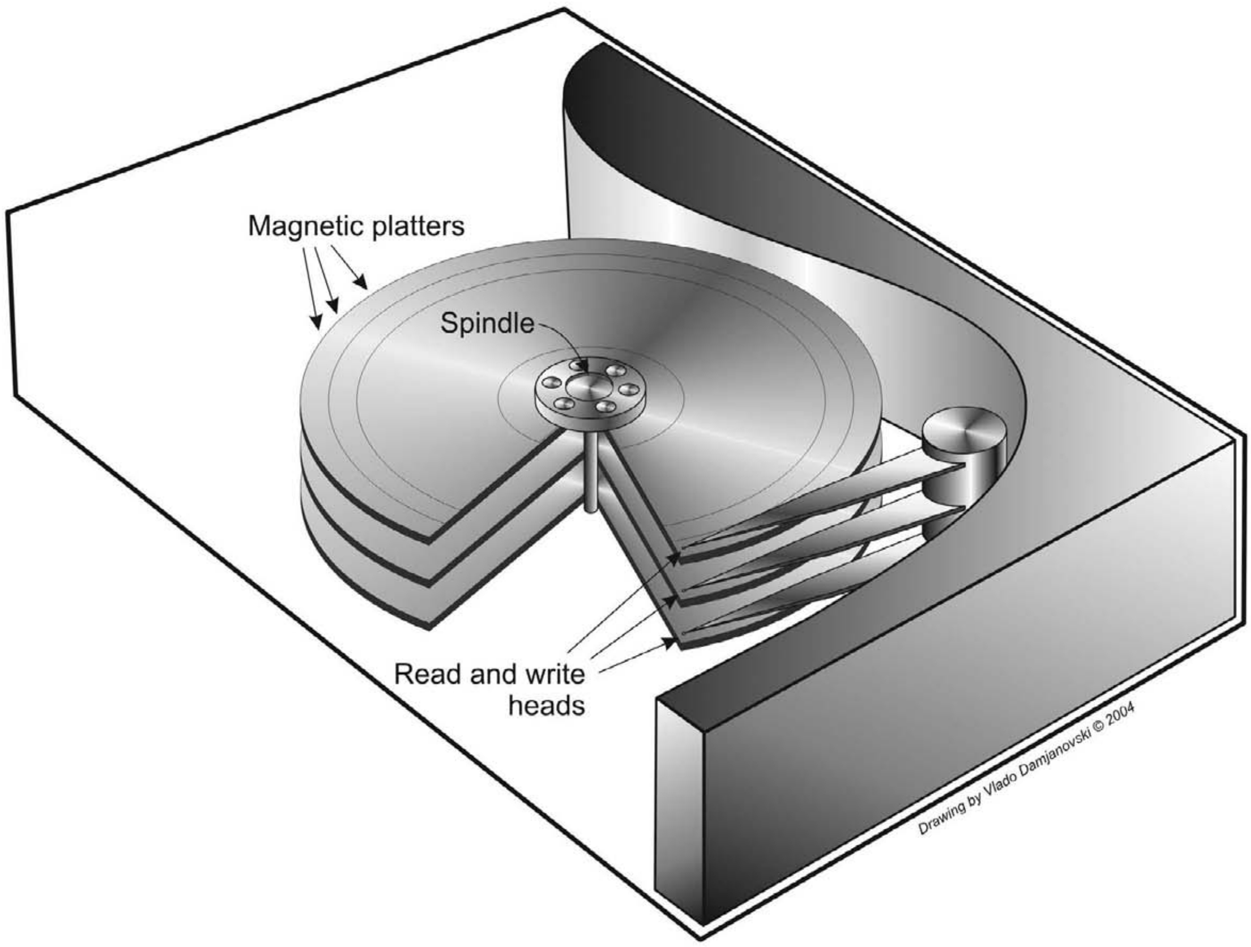


One of the most important electromechanical devices in DVRs

Hard disk drives

Hard disk drives are an essential part of any modern computer device, and this includes the DVRs in the digital CCTV. It is therefore very important to understand how they work and to learn what are their performances and limitations. A hard disk or hard drive is responsible for long-term storage of information. Unlike volatile memory (often referred to as RAM), which loses its stored information once its power supply is shut off, a **hard disk stores information permanently**, allowing you to save programs, files, and other data. Hard disks also have much greater storage capacities than RAM; in fact, current single hard disks may contain over 400 GB of storage space.

A hard disk is comprised of four basic parts: **platters, a spindle, read/write heads, and integrated electronics**. Platters are rigid disks made of metal or plastic. Both sides of each platter are covered with a thin layer of iron oxide or other magnetizable material. The platters are mounted on a central axle or spindle, which rotates all the platters at the same speed. Read/write heads are mounted on arms that extend over both top and bottom surfaces of each disk. There is at least one read/write head for each side of each platter. The arms jointly move back and forth between the platters' centers and outside edges. This movement, along with the platters' rotation, allows the read/write heads to access all areas of the platters. The integrated electronics translate commands from the computer and move the read/write heads to specific areas of the platters, thus reading and/or writing the needed data.



Main mechanical parts of a hard drive



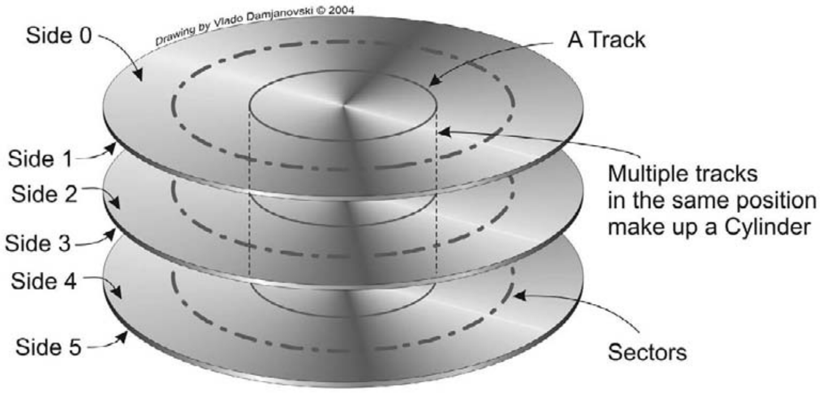
Two major sizes of hard drives: 3.5" used in desktop machines and 2.5" used in notebook computers

Computers record data on hard disks as a series of binary bits. Each bit is stored as a magnetic polarization (north or south) on the oxide coating of a disk platter. When a computer saves data, it sends the data to the hard disk as a series of bits. As the disk receives the bits, it uses the read/write heads to magnetically record or "write" the bits on the platters. Data bits are not necessarily stored in succession; for example, the data in one file may be written to several different areas on different platters. When the computer requests data stored on the disk, the platters rotate and the read/write heads move back and forth to the specified data area(s). The read/write heads read the data by determining the magnetic field of each bit, positive or negative, and then relay that information back to the computer. The read/write heads can access any area of the platters at any time, allowing data to be accessed **randomly** (rather than sequentially, as with a magnetic tape). Because hard disks are capable of random access, they can typically access any data within a few millionths of a second.

In order for a computer operating system (OS) to know where to look for the information on the hard disk, hard disks are organized into discrete, identifiable divisions, thus allowing the computer to easily find any particular sequence of bits. The most basic form of disk organization is called **formatting**. Formatting prepares the hard disk so that files can be written to the platters and then quickly retrieved when needed.

Before a brand new hard drive is used, it needs to be formatted. **Formatting is a method of organizing what is saved to the disk,** and it depends on the operating system (OS). **Hard disks must be formatted in two ways: *physically and logically*.** Physical formatting is done before a logical one.

Formatting is made in ***sectors, clusters (a group of sectors) and tracks*** according to the operating system used. Tracks are concentric circular paths written on each side of a platter, like those on a record or compact disc. The tracks are identified by number, starting with track zero at the outer edge. Tracks

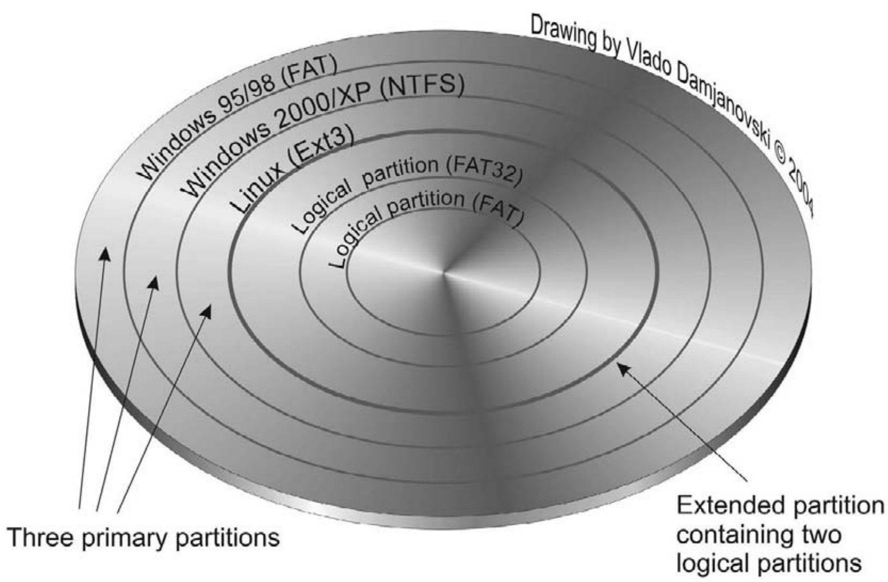


This is how cylinders are made – tracks on both sides of magnetic plates

are divided into smaller areas or sectors, which are used to store a fixed amount of data. Sectors are usually formatted to contain 512 bytes of data (there are 8 bits in a byte). A cylinder is comprised of a set of tracks that lie at the same distance from the spindle on all sides of all the platters. For example, track three on every side of every platter is located at the same distance from the spindle. If you imagine these tracks as being vertically connected, the set forms the shape of a cylinder. Computer hardware and software frequently work using cylinders. When data is written to a disk in cylinders, it can be fully accessed without having to move the read/write heads. Because head movement is slow compared to disk rotation and switching between heads, cylinders greatly reduce data access time.

After a hard disk is physically formatted, **the magnetic properties of the platter coating may gradually deteriorate**. Consequently, it becomes more and more difficult for the read/write heads to read data from or write data to the affected platter sectors. **The sectors that can no longer be used to hold data are called bad sectors**. Fortunately, the quality of modern disks is such that bad sectors are rare. Furthermore, most modern computers can determine when a sector is bad; if this happens, the computer simply marks the sector as bad (so it will not be used again) and then uses an alternate sector.

After a hard disk has been physically formatted, it must also be logically formatted. Logical formatting places a file system on the disk, allowing an operating system (such as Windows or Linux) to use the available disk space to store and retrieve files. Different operating systems use different file systems, so the type of logical formatting applied depends on the OS installed.



Partitioning

Formatting the entire hard disk with one file system limits the number and types of operating systems that can be installed on the disk. If, however, the disk is divided into partitions, each partition can then be formatted with a different file system, allowing multiple operating systems. Dividing the hard disk into partitions also allows the use of disk space to be more efficient.

To read or write data, the disk head must be positioned over the correct track on the rotating media. ***Seek times*** are usually quoted to include the time it takes for the head to stop vibrating after the move ("settling time"). Then a delay occurs until the correct data sector rotates under the head ("rotational latency"). Modern disks use accelerated track positioning, so that the head moves faster and faster until about the halfway point and then is decelerated to a stop at the target track. This is why the **average seek** is only a few times the **minimum seek**. The **maximum seek** time is usually about twice the average seek time because the head reaches its maximum speed before the middle track of the disk. The minimum track-seek time is the time it takes to move the heads from one track to the next adjoining track. For reading large blocks of data, such as our DVR recorded footage, this is the most significant seek performance value. The **average track seek time is more important** for random access of small amounts of data such as traversing a directory path.

Access Time is equal to the time to switch heads + time to seek the data track + time for a sector to rotate under the head + repeat for the next sector. More heads reduce the need to mechanically seek a new track.

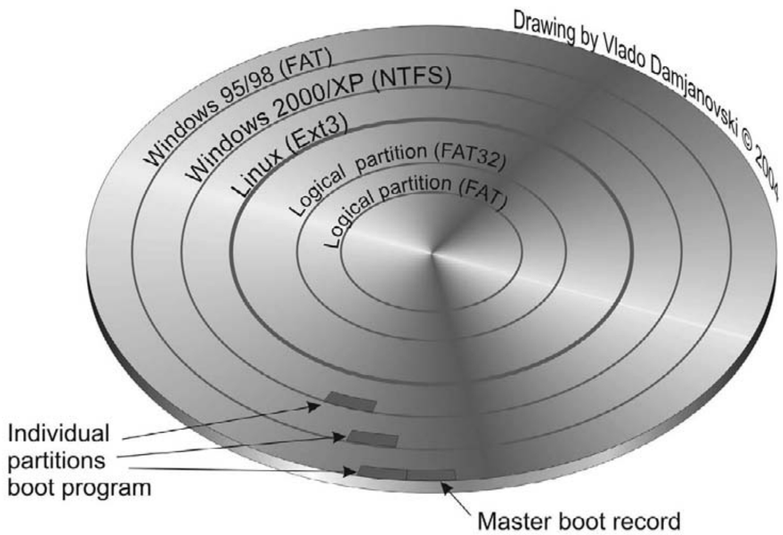
Faster rotational speed (spindle speed) increases the maximum data transfer rate and reduces the rotational latency. The rotational latency is the additional delay in seeking a particular data sector while waiting for that sector to come under the read head. The following table illustrates typical differences between various rotational speed hard drives and their maximum transfer rates (discussed later in the book), which are the most important indicator of how much data we can put through the magnetic plates of the hard disks.

Rotational Speed	Rotational Latency	Maximum (Burst) Transfer Rate
3600 rpm	16.7 ms	60 MB/s
4500 rpm	13.3 ms	80 MB/s
5400 rpm	11.1 ms	100 MB/s
7200 rpm	8.3 ms	140 MB/s
10,000 rpm*	6.0 ms	200 MB/s
12,000 rpm*	5.0 ms	250 MB/s
15,000 rpm*	4.0 ms	300 MB/s

*The higher speeds require better cooling of the drive.

Every hard disk is specified with its rotational speed or ***spindle speed***. Expressed in ***revolutions per minute*** (rpm), this specification gives a very good indication of the drive performance. Desktop drives generally come in 5400 rpm and 7200 rpm varieties, with 7200 rpm drives averaging 10% faster (and 10 to 30% more expensive) than 5400 rpm models. High-end 10,000 rpm and 15,000 rpm hard drives offer only marginally better performance than 7200 rpm drives and cost much more, in part because

they are typically SCSI drives with added reliability features. Also, higher spindle hard drives need more current; hence they get **hotter**. **Cooling is very important for all hard drives**, and more so for the faster ones. So, for a typical DVR, hard disks with 5400 rpm or 7200 rpm are a good compromise between sufficient speed, reasonable cost, and being relatively "cool" drives.



Location of boot records

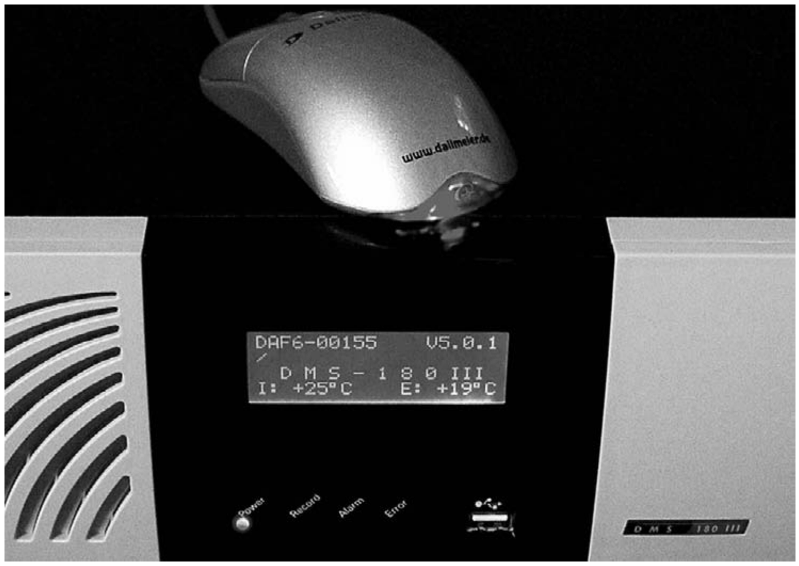
If two drives have the same spindle speed, the seek time shows which one is better. Differences in seek times, which range from 3.9 milliseconds (ms) for ultra-fast SCSI drives to 12 ms for slower IDE drives, may be noticeable in database or search applications where the head scoots all over the platter, but also when doing a VMD or time/date search in a digital recorder footage.

Cache is another term used in hard drives, and it refers to the **amount of memory built into the drive.** Designed to reduce disk reads, the cache holds a combination of the data most recently and most frequently read from disk. Large caches tend to produce greater performance benefits when multiple users access the same drive at once. Although small differences in cache size may have little bearing on performance, a smaller cache may be a sign of an older, slower drive. Operating systems try to maximize performance by minimizing the effect of mechanical activity. Keeping the most recently used data in memory reduces the need to go to the disk drive, move the disk heads, and so on. The writing of new data may also be cached and written to disk at a later, more efficient time. Other strategies include track buffering where data sectors are read into memory while waiting for the correct sector to rotate under the head. This can eliminate the delay of rotational latency because later sectors have already been read after reading of the sought sector is complete. For modern disks, this track buffering is usually handled by a memory cache on the disk drive's built-in controller. Modern disk drives usually have cache that ranges from 2 MB to 4 MB of cache memory to buffer track reads and hence eliminate rotational latency. Some high-end drives have 8 MB or even 16 MB. However, the rotational speed still limits the maximum transfer rate.



Larger hard disks usually have multiple heads and platters.

Despite the electronic methods of improving the hard disk's performance, they are determined primarily by the mechanical characteristics of the drive. This is the reason external factors affecting the mechanical performances of the hard disks also affect their reliability and lifetime expectancy. **Exposure to high temperatures, dust, moisture, shocks, and vibrations are external factors that can cause hard disk failures.**



One of the very few DVR manufacturers that takes good care of its hard drives by filtering the air, monitoring fans, external and internal temperature

High temperatures and dust are the two most common causes of hard disk failures we experience in practice in CCTV.

It is not unrealistic to say that hard drives in some DVRs work even harder than hard drives on many Internet web servers. Unfortunately, the culture of customers using DVRs is not the same as the culture of customers using company or web servers, for example. DVRs are very often mistreated and put in places with minimum air conditioning, often plenty of dust, and various evaporations. In all CCTV system designs, we must insist on treating hard disks the same way as when they are running inside the company servers.

In the current race of making more and better DVRs, most CCTV manufacturers concentrate on having higher compressions or recording more frames per second. Few among them have gone in the direction of taking care of the actual DVR environment, filtering the cooling air, measuring the fan's revolution, as well as external and internal temperature. In addition to using a stable OS, these are extremely important factors influencing the longevity of the DVRs. At the end of the day, it is no good having even the highest frame rate if they cannot be saved on a healthy hard disk.

There are a variety of hard disk interface standards between the computer and the hard disks, such as ATA, SCSI, RAID, and SATA, all of which are discussed later on in the book. Each one has its own advantages and disadvantages, but the bottom line is the hard disk itself.

The hard disk sustained data transfer rate ultimately defines how many cameras or images per second a DVR can have. This is the bottleneck of data transfer as it depends on mechanically moving parts. The sustained transfer rate is always less than the burst transfer rate. Generally ranging from 14 MB/s to 60 MB/s (mega bytes per second!), it indicates how fast data can be read from the outermost track of a hard drive's platter into the cache. **The sustained transfer rate is an important parameter of the DVRs' hard drives, which ultimately defines the upper limit of how many pictures per second your system can record and play back.**

This performance also depends on the operating system, the processor, and the compression speed, file sizes, and the like, but ultimately, if the hard drive cannot cope with such a through-output the DVR

cannot achieve what it is (theoretically) capable of.

Let us analyze this issue with one practical example:

Let us be conservative and assume that we have a typical and "not-so-good" hard disk with a sustained transfer rate of only 14 MB/s. If we translate this rate into mega bits per second we should multiply 14 by 8, and we get a 112 Mb/s transfer rate. Let us now assume that we are recording on a DVR with JPG compression that records good-quality images of, let us say, 40 kB. If we do not do anything else while the recorder records (i.e., not playing back); to find out what the maximum (theoretical) recording performance of such a machine is we need to divide 14 MB/s by 40 kB. This gives a number of 350. If we have 16 cameras connected to the DVR, then the theoretical maximum recording rate will be 350/16 = 21 pictures per second per camera. This is a theoretical maximum of a DVR where no other processes are active. In reality, the DVR has to "spend time" doing time base correction, i.e., synchronizing the un-synchronized cameras. This will reduce the theoretical rate by at least 50% to 10 pictures per second per camera. If we decide to play back at the same time, or archive, this would further reduce the recording performance by another factor of at least 50%, obtaining 5 pictures per second per camera as a theoretical maximum with such a hard drive. In addition, the intelligence of the operating system of handling files has to be considered. And this is all true if we assume that our example DVR does hardware JPEG compression at a faster rate, hence not "wasting" the operating system and main processor's time. In many practical DVRs you will find that the compression might be done by the "proprietary software encoding scheme." This practically means that there will be some additional "bottlenecks" for our theoretical recording performance, which most likely would drop down from the above calculated 5 pictures per second to maybe 1 or 2 pictures per second per camera. And, there is one more important, and almost invisible, factor that we need to consider in this example.

This is the point where we have to acknowledge that the fragmenting of files while performing continuous recording (24 hours a day, 7 days a week) is handled by the operating system and can affect the recording performance, especially after a longer period of recording of a few days or weeks. No number can be attached to this performance reduction factor, for it depends on the DVR software design, but it is going to reduce the performance further, although the actual hard disk sustained transfer rate might be unaffected. (The hard disk "wastes time" searching for the free fragments as dictated by the operating system.)

As can be concluded from the above example, many factors influence the performance of a digital video recorder, not just the "DVR front end," but other underlying and invisible processes as well. The hard drives are the starting and the ending point in such a chain of operation.



A typical DVR in CCTV has 16 camera inputs, but 18, 24, or 32 are also possible.

The different file systems

Each different operating system uses some kind of file system in order to write data on hard drives and removable media, so that later on the user is able to find it and read it. Inherently, this is a fundamental and important concept that defines the flexibility, capacity, and security of various systems. This is why we will mention the most common ones here.

All file systems consist of structures necessary for storing and managing data. These structures typically include an operating system boot record, directories, and files.

A file system performs three main functions: it tracks the allocated and unused space; it maintains directories and filenames; and it tracks the physical coordinates where each file is stored on the disk.

Different file systems are used by different operating systems. Some operating systems (such as Windows) can recognize only some of its own file systems, while others (such as Linux and Mac OSX) can recognize several, including the ones from other OSs.

Some of the most common file systems in use today are:

Ext – Extended file system, designed for Linux systems

Ext2 – Extended file system 2, designed for Linux systems

Ext3 – Extended file system 3, designed for Linux systems (Ext2+journaling)

FAT – Used on DOS and Microsoft Windows, working with 12 and 16 bits

FAT32 – FAT with 32 bits

HFS – Hierarchical File System, used on older Mac OS systems

HFS+ – Used on newer Mac OS systems

HPFS – High Performance File system, used on IBM’s OS/2

ISO 9660 – Used on CD and DVD-ROM disks (Rock Ridge and Joliet are extensions to this)

JFS – IBM Journaling File system, provided in Linux, OS/2, and AIX

NTFS – Used on Windows NT-based systems (Windows 2000 and XP)

ReiserFS – File system that uses journaling, used in Linux and Unix

UDF – Packet-based file system for WORM/RW media such as CD-RW and DVD

UFS – Unix and Mac OS X File system

FAT (File Allocation Table)

Introduced by Microsoft in 1983, the ***File Allocation Table*** (FAT) is a file system that was developed for MS-DOS and used in consumer versions of Microsoft Windows up to and including Windows ME. Even with 512-byte clusters, this could give up to 32 MB of space – enough for the 10 MB or 20 MB XT hard drives that were typical at the time. As hard drives larger than 32 MB were released, large cluster sizes were used. The use of 8192-byte clusters allowed for file system sizes up to 512 MB. However, this increased the problem of internal fragmentation where small files could result in a great deal of wasted space; for example, a 1-byte file stored in a 8192-byte cluster results in 8191-bytes of wasted space.

The FAT file system is considered relatively uncomplicated, and because of that, it is a popular format for floppy disks. Moreover, it is supported by virtually all existing operating systems for personal computers, and because of that it is often used to share data between several operating systems booting on the same computer (a multi-boot environment). It is also used on solid-state memory sticks and other similar devices.



Hard disk, CD-ROM, and floppies

The FAT file system also uses a root directory. This directory has a maximum allowable number of entries and must be located at a specific place on the disk or partition.

Although it is one of the oldest file formats, FAT is likely to remain for a long time because it is an ideal file system for small drives, like the floppies. It is also used on other removable storage for noncomputer devices, such as flash memory cards for digital cameras, USB flash drives, and the like.

FAT32 (File Allocation Table 32)

In 1997, Microsoft created FAT32 as an extension to the FAT concept because the cluster growth possibility was exhausted. The largest cluster size in Windows FAT was 32 kB, giving a maximum volume size of 2 GB. Microsoft decided to implement a newer generation of FAT, known as FAT32, with 32-bit cluster numbers, of which 28 bits are currently used. In theory, this should support a total of approximately 268,435,438 clusters, allowing for drive sizes in the multi-terabyte range. However, due to limitations in Microsoft's ScanDisk utility, the FAT is not allowed to grow beyond 4,177,920 clusters, placing the volume limit at 124.55 GB.

This is an enhancement of the FAT file system and is based on 32-bit file allocation table entries, rather than the 16-bit entries used by the previous FAT system. As a result, FAT32 supports

much larger disk or partition sizes (up to 2 TB). This file system can be used by Windows 95 SP2 and Windows 98/2000/XP. Previous versions of DOS or Windows cannot recognize FAT32 and are thus unable to boot from or use files on a FAT32 disk or partition. The FAT32 file system uses smaller clusters than the FAT file system, has duplicate boot records, and features a root directory that can be of any size and can be located anywhere on the disk or partition.

NTFS (New Technology File System)

NTFS or ***New Technology File System*** is the standard file system of Microsoft Windows NT and its descendants, Windows 2000, Windows XP, and Windows Server 2003. NTFS is a descendant of HPFS, the file system designed by Microsoft and IBM for OS/2 as a replacement for the older FAT file system of MS-DOS. HPFS has several improvements over FAT such as support for metadata and the use of advanced data structures in order to improve performance, reliability, and disk space utilization. NTFS incorporates these plus additional extensions such as security access control lists and file system journaling.

In NTFS everything that has anything to do with a file (name, creation date, access permissions, and even contents) is written down as metadata. Internally, NTFS uses binary trees in order to store the file system data; although complex to implement, this allows fast access times and decreases fragmentation. A file system journal is used in order to guarantee the integrity of the file system itself (but not of each individual file). Systems using NTFS are known to have improved reliability, a particularly important requirement considering the unstable nature of the older versions of Windows NT.

Because details on the implementation's details are closed, third-party vendors have a difficult time providing tools to handle NTFS. Currently, the Linux kernel includes a module that makes it possible to read NTFS partitions. However, the general complexity of the file system and inadequate developer resources, both in time and persons, have delayed the addition of full write support.

NTFS is not recommended for use on small hard disks because it uses a great deal of space for system structures. The central system structure of the NTFS file system is the **master file table** (MFT). NTFS keeps multiple copies of the critical portion of the MFT to protect against corruption and data loss. Like FAT and FAT32, NTFS uses clusters to store data files. However, the size of the clusters is not dependent on the size of the disk or partition. A cluster size as small as 512 bytes can be specified, regardless of whether a partition is 6 GB or 60 GB. Using small clusters not only **reduces the amount of wasted disk space**, but **also reduces file fragmentation**, a condition where files are broken up over many noncontiguous clusters, resulting in slower file access. Because of its ability to use small

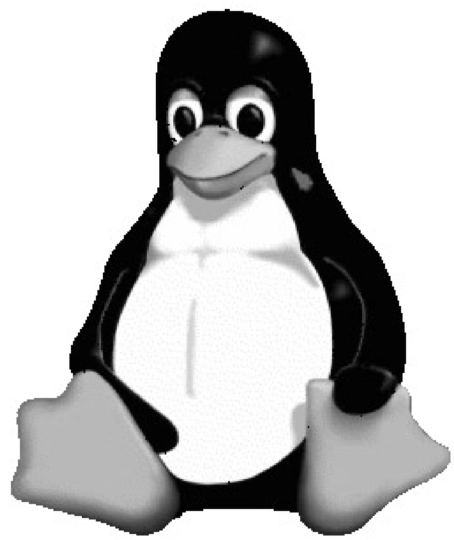
clusters, NTFS provides good performance on large drives. Finally, the NTFS file system supports hot fixing, a process through which bad sectors are automatically detected and marked so that they will not be used.

Ext2

The Ext2 or ***second extended file system*** was the standard file system used on the Linux operating system for a number of years and remains in wide use. It was initially designed by Rémy Card based on concepts from the extended file system. It is quite fast, enough so that it is used as the standard against which to measure many benchmarks. Its main drawback is that it is not a journaling file system. The Ext2 file system supports a maximum disk or partition size of 4 terabytes. Its successor, Ext3, has a journal and is compatible with Ext2.

Ext3

The Ext3 or ***third extended file system*** is a journaled file system that is coming into increasing use among users of the Linux operating system. Although its performance and scalability are less attractive than those of many of its competitors such as ReiserFS and XFS, it does have the significant advantage that users can upgrade from the popular Ext2 file system without having to back up and restore data.



The Ext3 file system adds a journal without which the file system is a valid Ext2 file system. An Ext3 file system can be mounted and used as an Ext2 file system. All of the file system maintenance utilities for maintaining and repairing the Ext2 file system can also be used with the Ext3 file system, which means Ext3 has a much more mature and well-tested set of maintenance utilities available than do its rivals.

ReiserFS

The ReiserFS is a general-purpose computer file system designed and implemented by a team at ***Namesys*** led by ***Hans Reiser***. It is currently supported by Linux and may be included in other operating systems in the future. Introduced with version 2.4.1 of the Linux kernel, it was the first journaling file system to be included in the standard kernel.

The most publicized advantage over what was the stock Linux file system at the time, Ext2, is that it uses a transaction **journal** to record changes to file system structures. **The journal allows the file system to quickly return to a consistent state after an unscheduled system shutdown caused by a**

power outage or a system crash. This feature greatly **reduces the risk of file system corruption** (and the need for lengthy file system checks). ReiserFS also handles directories containing huge numbers of small files very efficiently. Unfortunately, converting a system to ReiserFS requires users of Ext2 to completely reformat their disks, which is a disadvantage not shared by its main competitor Ext3. Because of its advantages, many Linux distributions have made it the default file system.

HFS and HFS+

HFS Plus or HFS+ is a file system developed by Apple Computer to replace its ***Hierarchical File System*** (HFS) as the primary file system used on Macintosh computers. It is also one of the formats used by the iPod hard-disk based music player. HFS Plus was introduced with the January 19, 1998, release of Mac OS 8.1. This format is also referred to as Mac OS Extended.

HFS Plus is an improved version of HFS, supporting much larger files (64-bit length instead of 32 bit) and using Unicode (instead of MacRoman) for naming the items (files, folders). HFS Plus permits filenames up to 255 characters in length. HFS Plus also uses a full 32-bit allocation mapping table rather than HFS's 16 bits. This was a serious limitation of HFS, meaning that no disk could support more than 65,536 sectors under HFS. When disks were small, this was of little consequence, but as they started to approach the 1 GB mark, it meant that the smallest amount of space that any file could occupy (a single sector) became excessively large, wasting significant amounts of disk space. Like HFS, HFS Plus uses B-trees to store most volume metadata.

With the release of the 10.2.2 update on November 11, 2002, Apple added optional journaling features to HFS Plus for improved data reliability. These features were easily accessible in the Mac OS X Server, but were only accessible through the command line in the standard desktop client. However, in 2003 Mac OS X version 10.3 set all HFS Plus volumes on all Macs to be journaled by default.

XFS

XFS is a high-performance journaling file system created by SGI (Silicon Graphics Inc.) for their Irix Unix implementation. In May 2000, SGI released XFS under an open source license. It comes by default with the 2.5.xx and 2.6.xx versions of the Linux kernel, but it was not available to the 2.4.xx kernel, except as a patch, until version 2.4.25 when it was stable enough to be merged into the main development.

UFS

The UNIX file system (UFS) is used by many Unix operating systems. It is derived from the ***Berkeley Fast File System*** (FFS), which itself was originally developed from FS in the first versions of UNIX developed at Bell Labs.

Nearly all BSD Unix derivatives including FreeBSD, NetBSD, OpenBSD, NeXTStep, and Solaris, use a variant of UFS. In Mac OS X it is available as an alternative to HFS. In Linux, partial UFS support is available, and the native linux Ext2 file system is derived from UFS.

Mac OS X is the latest version of the Mac OS operating system for Macintosh computers. Developed and published by Apple Computer, it provides the stability of a Unix operating environment and adds popular features of the traditional Macintosh user interface. The operating system was first commercially released in 2001.

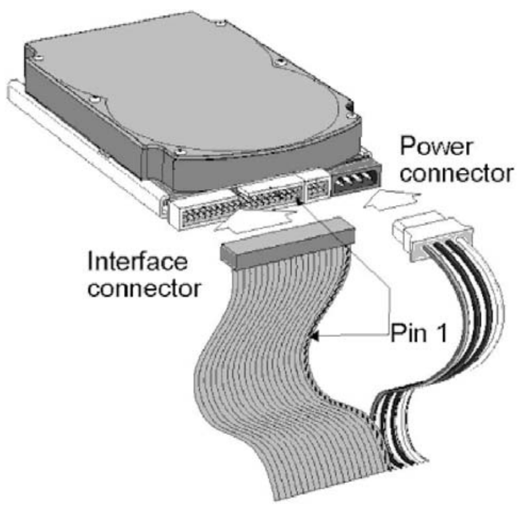
ATA, SCSI, RAID, and SATA

The type of connection between the hard drive and the system (motherboard and CPU) is defined by one of a few standards.

The most popular are the ***Enhanced Integrated Drive Electronics*** drives (**EIDE),** which are also known as ***Advanced Technology Attachment*** **(ATA)** drives.

Another format that used to be very popular, but is now used much less, is the ***Small Computer System Interface*** **(SCSI)**. The reason for having less SCSIs in CCTV is that the ATA drives have become comparable in speed and reliability, at a lower cost.

The ATA drives dominate the PC industry, and this is the case with the DVRs as well.



The ATA (EIDE) parallel standard

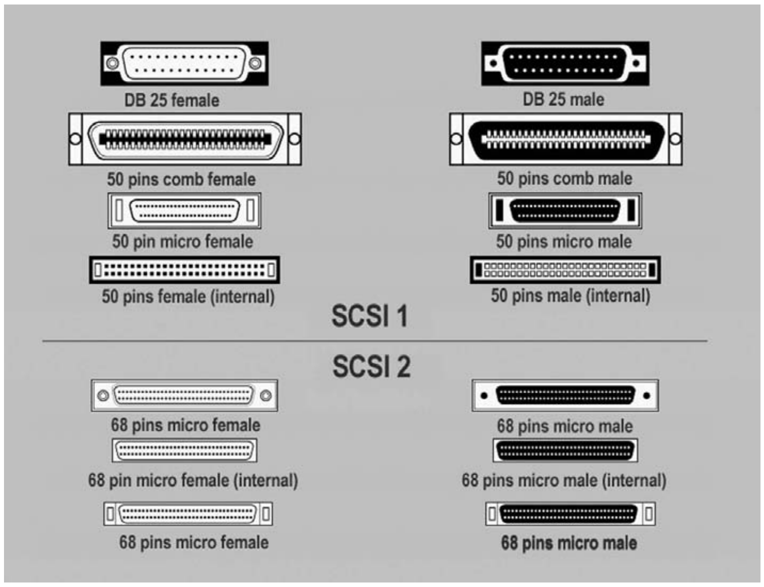
Most modern PCs can talk to up to four EIDE drives without any additional hardware. This is because the EIDE controller is usually embedded in the motherboards. Although this could also be the case with the SCSI controllers, it is not so frequent, especially in the last few years when the speed of ATA drives has become comparable to SCSI.

This is why most DVRs in CCTV can have up to four internal hard drives, providing, of course, there is physical space for them.

Year	1991	1994	1996	1998	2000	2002
SCSI type	SCSI	Wide SCSI	UltraWide SCSI	Ultra2 SCSI	Ultra3 SCSI (160)	Ultra3 SCSI (320)
Bus speed	5/10 MB/s	10/20 MB/s	20/40 MB/s	80 MB/s	160 MB/s	320 MB/s
Drive speed	2.5 MB/s	5 MB/s	10 MB/s	20 MB/s	40 MB/s	80 MB/s

The evolution of SCSI standards

Current EIDE drives generally conform to the ATA/100 or ATA/133 specification. The 100 in ATA/100 indicates that up to 100 MB/s (megabytes per second) can be transferred from the drive to the system in short bursts, and similarly the ATA/133 indicates up to a 133 MB/s **burst transfer rate**. It should be noted that the sustained transferred rate is usually around half of the burst rate.



The various SCSI connectors

Typically, only servers or large storage machines use SCSI drives, which cost much more and require an interface card. SCSI is designed to "talk to" more than four drives (usually up to 16 devices, one of which is the SCSI card). This is one more reason for using SCSI with larger storage capacity machines, although it is a costlier option.

There are a few generations of SCSI standard; usually the latest has the fastest transfer speed.

The prevailing SCSI specifications, Ultra160 and Ultra 320, support faster, 160 MB/s and 320 MB/s (respectively) burst transfer rates.



RAID works with redundancy and uses hot swappable ATA drives.

Lately, with the increased demand for more storage but also increased redundancy, devices called RAID are becoming more popular in CCTV.

RAID stands for ***Redundant Arrays of Inexpensive Disks*,** and the name describes its concept. It combines multiple small, inexpensive disk drives (usually ATA) into an array of disk drives that yields performance or redundancy. If one drive fails, data is not lost and there is usually a way to remove it and replace it while running. RAID usually requires interface electronics, like the SCSI, and this array of drives appears to the computer as a single logical storage unit or drive.

There are two considerations in selecting the right hard drives for RAID usage: drive capacity and rotational speed. Today's interfaces correspond exclusively to UltraATA/100 or even UltraATA/133, so they are always fast enough. High rotational speeds allow maximum data transfer rates and minimal access times, but they are accompanied by an increase in both heat and operating noise. RAID can principally be used with any hard drive.

Six types of array architectures are known today, RAID-1 through RAID-6, and each provides disk fault-tolerance (redundancy), with different tradeoffs in features and performance. In addition to these six redundant array architectures, it has become popular to refer to a non redundant array of disk drives as a RAID-0 array. The following is a summary of the seven different RAID versions:

RAID-0 (Striping)

This is the fastest and most efficient array type but offers no fault-tolerance, that is, no redundancy. So, technically speaking, RAID mode 0 does not adhere to the principles of a RAID. Hence RAID 0 offers no advantages in terms of security. All of the data are evenly distributed to all of the existing drives, which is usually referred to as **stripe set**. The only benefit of RAID-0 is speed – the data transfer rate is increased by the number of drives. If even one of those drive crashes, however, all of the stored data will be lost.

RAID-1 (Mirroring)

RAID-1 is basically the complete opposite of RAID-0. The goal here is not to boost performance but to ensure data security. When reading or writing data, all drives of the array are used simultaneously. Hence, data is written synchronously to two or more drives, which is equivalent to a perfect backup copy – perfect because the data is always 100% up to date. **RAID-1 is the array of choice for performance-critical, fault-tolerant environments**.

RAID-2 (Striping)

Striping in RAID-2 is based on the same principle as RAID-0: **the stripe set distributes the data to all drives**, though not in block form, but, rather, on a bit level. This is necessary because an Error Correcting Code (ECC) is implemented in all transaction data. Additional hard drives are necessary to store the resulting additional volume. If you wanted to guarantee complete data security, you would have to deploy at least 10 data disks and 4 ECC disks. The next level would entail 32 data disks and 7 ECC disks. This explains why RAID-2 never caught on.

RAID-3 (Data Striping, Dedicated Parity)

RAID-3 incorporates prudent error correction. **Data is allocated byte by byte to several hard drives, whereas the parity data is stored in a separate drive**. This is exactly the disadvantage of RAID-3, as the parity drive has to be accessed with every access. So the advantage of RAID, bundling the disk performance by distributing access, is partially offset. RAID-3 needs a minimum of three drives and it requires quite a complex controller, which is why RAID-3, similar to levels 4 and 5, never caught on in the mass market. RAID-3 drives are used in data-intensive or single-user environments that access long sequential records to speed up data transfer. However, RAID-3 does not allow multiple I/O operations to be overlapped and requires synchronized-spindle drives in order to avoid performance degradation with short records.

RAID-4 (Data Striping, Dedicated Parity)

The technology of RAID-4 is similar to that of RAID-3, except that the individual stripes are not written in bytes but in blocks. In theory, this should speed things up, but the parity drive still remains the bottleneck. So, RAID-4 offers no advantages over RAID-5 and does not support multiple simultaneous write operations.

RAID-5 (Distributed Data, Distributed Parity)

RAID-5 is generally considered the best compromise between data security and performance. Not only the data, but also the parity information, is distributed to all the existing drives. The resulting advantage is that RAID is only a bit slower than RAID 3. However, failure safety is limited, as only one hard drive can safely crash. At least three hard drives are required in each case. RAID-5 is a good choice in multi-user environments that are not write performance sensitive.

RAID-6 (Distributed Data, Distributed Parity)

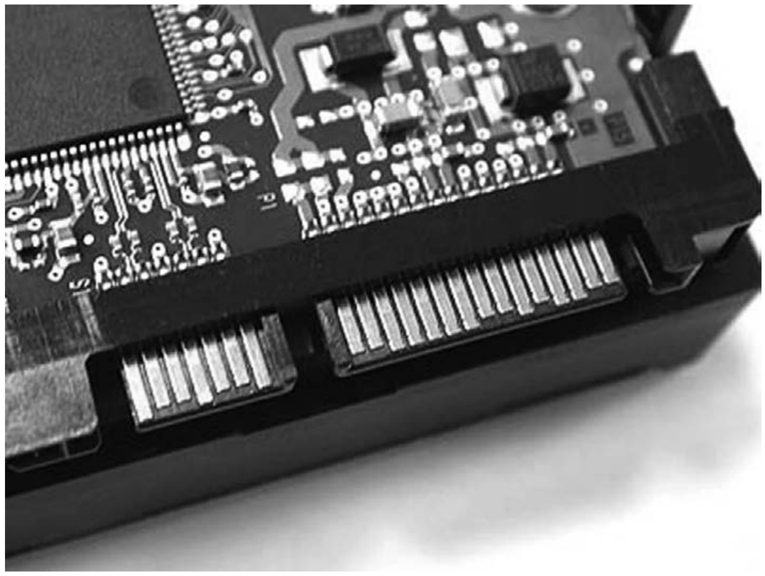
RAID-6 is very similar to RAID-5, except that twice the amount of parity information is stored. Although this cuts down on performance a bit, it allows up to two hard drives to crash. It does, however, require a minimum of five drives.

RAID is becoming more popular in CCTV because it offers extended recording time and redundancy. Most commonly used is RAID-5, although some manufacturers offer RAID-1 mirroring.

The latest standard interface between a computer motherboard and hard disks is the **Serial ATA** (SATA). The SATA has evolved from the legacy parallel ATA standard, and **it has three main advantages over its predecessor: speed, cable management, and hot-swappability**.

Initially, Serial ATA was released at 150 MB/s, but it is designed to scale up quite substantially from there. It is expected that SATA v.2.0 will double throughput to 300 MB/s, and 600 MB/s is planned for around 2007. The current SATA transfer rate of 150 MB/s is still only 17 MB/s faster than the fastest parallel ATA interface ATA/133. Parallel buses have difficulty in reaching ever higher speeds due to problems keeping all the data lines in sync. Serial ATA uses the new standards for signaling. Still,

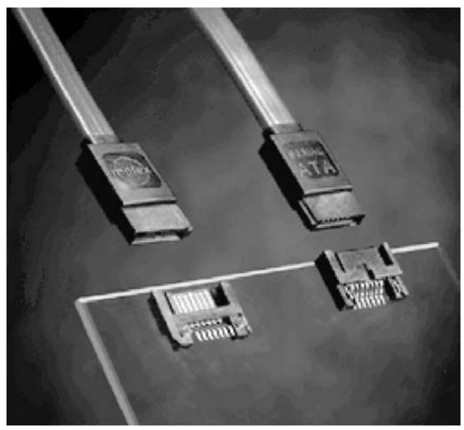
the need for such a high-speed interface could be debated as hard disks are almost always a bandwidth bottleneck, being mechanical devices.



Serial ATA hard drive connectors

Physically, the cables used are the largest change. The data is carried by a light flexible seven-conductor wire with 8 mm wide wafer connectors on each end. It can be anywhere up to 1 meter long. Compared to the short (45 cm), ungainly 40 or 80 conductor ribbon cables of parallel ATA, this will come as a great relief to system builders. In addition, airflow and therefore cooling in equipment will be improved. The concept of a master-slave relationship between devices has been dropped. SATA has only one device per cable. The connectors are keyed so that it should no longer be possible to install cable connectors upside down, which often is a problem with IDE types.

Native SATA hard disks also require a different power connector as part of the standard. It is wafer based but wider than the data cable, so it should not be possible to confuse the two. Fifteen pins are used to supply three different voltages if necessary – 3.3 V, 5 V, and 12 V. The same physical connections are used on 3.5" and 2.5" (notebook) hard disks. In the transitional period between parallel and serial ATA, various adapters are planned to convert one to the other. To perform the serial to parallel translation or vice versa, a bridge is used. There is a noticeable performance penalty for such an arrangement, however, and tests conducted in early 2003 show throughput reduced around 30 to 50%. Many hard drive manufacturers, however, now produce native Serial ATA hard drives.



Serial ATA cables

MTBF (Mean Time Between Failure)

A majority of hard disk manufacturers quote **MTBF (Mean Time Between Failure)** numbers for their hard drives. Typical hard disk MTBF numbers are anything between 300,000 and 1,000,000 hours. This is quite a high number, equivalent to 30 to 100 years. These numbers are more **theoretical,** rather than a guarantee. Technology does not allow hard drives to be used for more than a couple of years; they are quickly outdated, but mathematical calculation and statistical experience offer an important indicator about the hard disk life quality and life expectancy.

Practice has shown that hard drives fail sooner than their MTBF predicts. Some of the main reasons (apart from the quality of manufacture) are, as we already mentioned, physical mistreatment (shocks and vibrations), temperature (insufficient cooling), and dust.

The MTBF is based on a simple exponential distribution of failure

$$\text{Failure Probability} = R(t) = e^{\frac{-t}{M}} = e^{-\lambda t} \qquad (47)$$

where e is the natural base number $e = 2.71$, t is the time for which this probability is calculated, and M is the MTBF. So, for example, for a 500,000 hour MTBF drive there is 1% probability it will fail in 7 months, 5% in 3 years, 10% in 6 years, and 50% in 40 years.



10. Transmission media

Once the image has been captured by a lens and a camera and then converted into an electrical signal, it is further taken to a switcher, a monitor, or a recording device.

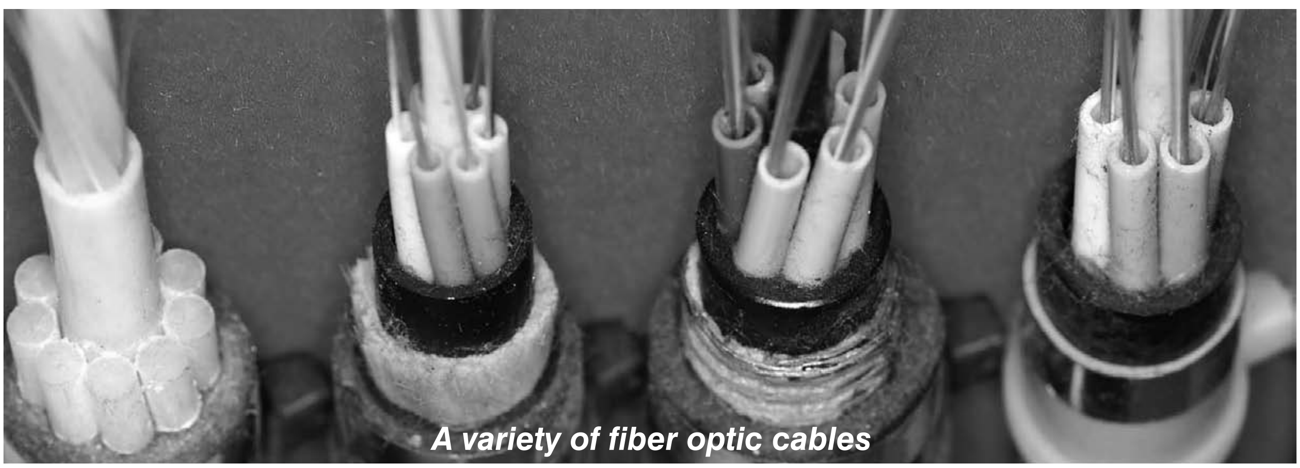
In order for the video signal to get from point A to point B, it has to go through some kind of transmission medium. The same applies to the control-data signal.

The most common media for video and data transmission in CCTV are as follows:

- Coaxial cable
- Twisted pair cable
- Microwave link
- RF open-air transmission
- Infrared link
- Telephone line
- Fiber optics cable
- Network

For video transmission, a coaxial cable is most often used, but fiber optics is becoming increasingly popular with its superior characteristics. Mixed means of transmission are also possible, such as video via microwave and PTZ control data via twisted pair, for example.

We will go through all of them separately, but we will pay special attention in this chapter to the coaxial cable and fiber optics transmission. Network transmission has become so important to CCTV in the last half a dozen years that we have a separate chapter dedicated to this topic.



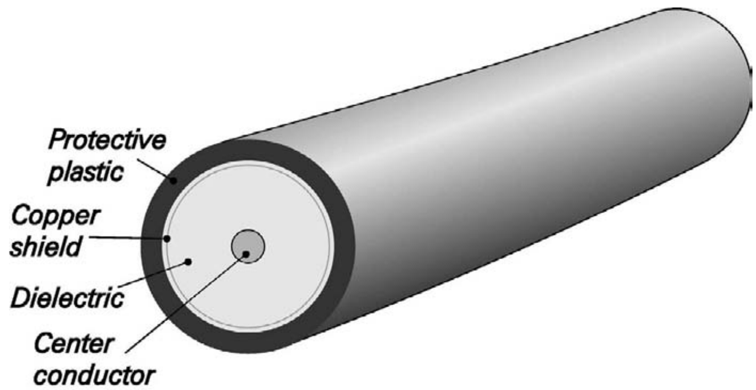
A variety of fiber optic cables

Coaxial cables

The concept

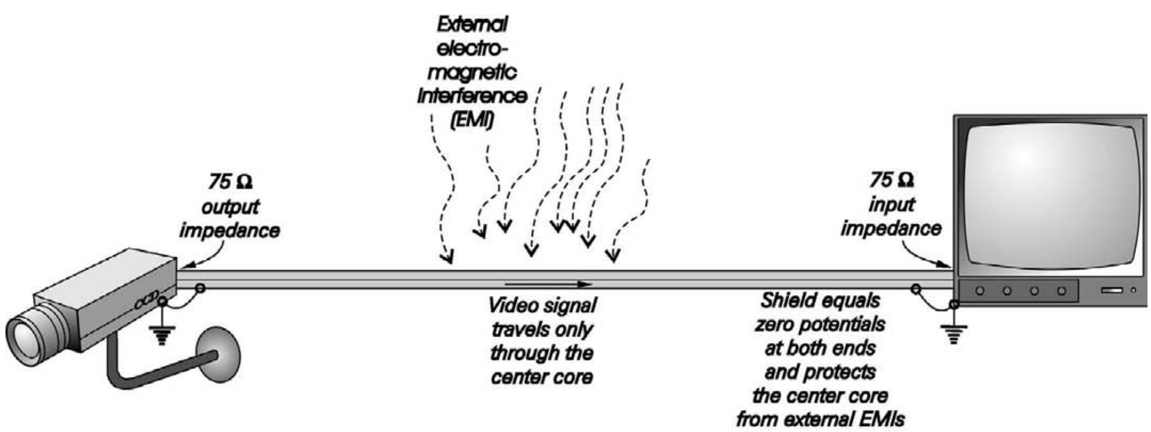
The ***coaxial cable*** is the most common medium for transmission of video signals and sometimes video and PTZ data together. It is also known as ***unbalanced*** transmission, which comes from the concept of the coaxial cable (sometimes called "***coax***" for short).

A cross section of a coax is shown to the right. It is of a symmetrical and coaxial construction. The video signal travels through the center core, while the shield is used to common the ground potential of the end devices – the camera and the monitor, for example. It not only commons the ground potential, but also serves to protect the center core from external and unwanted electromagnetic interference (EMI).



Cross section of a coaxial cable

The idea behind the coaxial concept is to have all the unwanted EMI induced in the shield only. When this is properly grounded, it will discharge the induced noise through the grounds at the camera and monitor ends. Electrically, the coaxial cable closes the circuit between the source and the receiver, where the coax core is the signal wire, while the shield is the grounding one. This is why it is called an unbalanced transmission.

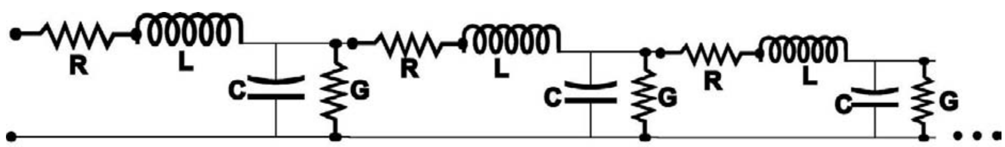


Video transmission over coaxial cable

Noise and electromagnetic interference

How well the coax shield protects the center core from noise and EMI depends on the percentage of the screening. Typically, numbers between 90 and 99% can be found in the cable manufacturer's specifications. Have in mind, however, even if the screening is 100%, that it is not possible to have 100% protection from external interference. The penetration of EMI inside the coax depends on the frequency.

Theoretically, only frequencies above 50 kHz are successfully suppressed, and this is due mostly to the skin-effect attenuation. All frequencies below this will induce current in smaller or bigger form. The strength of this current depends on the strength of the magnetic field. Our major concern would be, obviously, the mains frequency (50 or 60 Hz) radiation, which is present around almost all artificial objects.



Theoretical representation of a coaxial cable

This is why we could have problems running a coaxial cable parallel to the mains. The amount of induced electromagnetic voltage in the center core depends first on the amount of current flowing through the mains cable, which obviously depends on the current consumption on that line. Second, it depends on how far the coax is from the mains cable. And last, it depends on how long the cables run together. Sometimes 100 m might have no influence, but if strong current is flowing through the mains cable, even a 50 m run could have a major influence. When installing, try (whenever possible) not to have the power cables and the coaxial cables very close to each other; at least 30 cm would be sufficient to notably reduce the EMI.

The visual appearance of the induced (unwanted) mains frequency is a few thick horizontal bars slowly scrolling either up or down. The scrolling frequency is determined by the difference between the video field frequency and the mains frequency and can be anything from 0 to 1 Hz. This results in stationary or very slow-moving bars on the screen.

Other frequencies will be seen as various noise patterns, depending on the source. A rule of thumb is that the higher the frequency of the induced unwanted signal, the finer the pattern on the monitor will be. Intermittent inducting, like lightning or cars passing by, will be shown as an irregular noise pattern.

Characteristic impedance

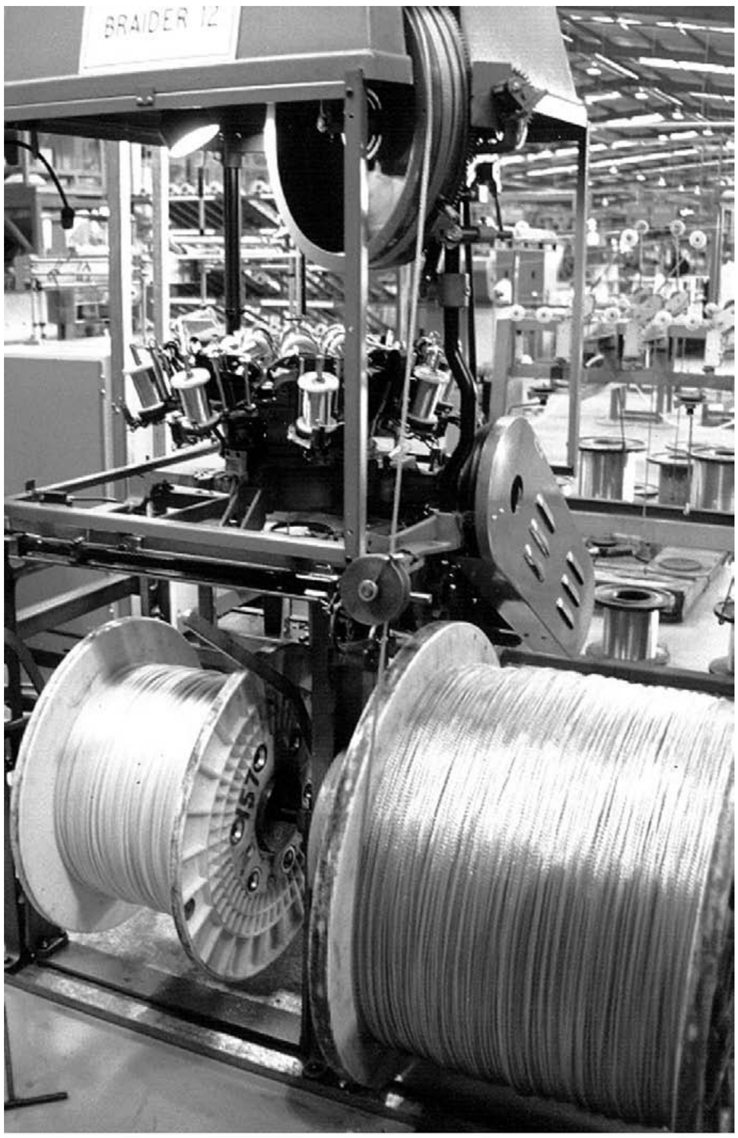
Short wires and cables used in an average electronic piece of equipment have negligible resistance, inductance, and capacitance, and they do not affect the signal distribution. If a signal, however, needs to be transmitted for a longer distance, many factors add up and contribute to the complex picture of such transmission media. This especially influences high-frequency signals. Then, the resistance,

inductance, and capacitance play a considerable role and visibly affect the transmission.

A simple medium like the coaxial cable, when analyzed by the electromagnetic theory, is approximated with a network of resistors (R), inductors (L), capacitors (C), and conductors (G) per unit length (as shown on the diagram on the previous page). For short cable runs this network has a negligible influence on the signal, but for longer runs it becomes noticeable. In such a case the network of R, L, and C elements becomes so significant that it acts as a crude low-pass filter that, in turn, affects the amplitude and phase of the various components in the video signal. The higher the frequencies of the signal, the more they are affected by these nonideal cable properties.

Each cable is **uniformly** built and has its own ***characteristic impedance***, which is defined by the R, L, C, and G per unit length.

The main advantage of the unbalanced video transmission (which will be shown a little bit later) is based on the fact that **the characteristic impedance of the medium is independent of the frequency** (refers mainly to the mid and high frequencies), while the phase shift is proportional to the frequency.



Coaxial cable braiding machine

The amplitude and phase characteristics of the coax at low frequencies is very dependent on the frequency itself, but since the cable length in such cases is reasonably short compared to the signal wavelength, it results in negligible influence on the signal transmission.

When the characteristic impedance of the coaxial cable is matched to the video source output impedance and the receiving unit input impedance, it **allows for a maximum energy transfer between the source and the receiver.**

For high-frequency signals, as is the video, impedance matching is of paramount importance. **When the impedance is not matched, the whole or part of the video signal is reflected back to the source, affecting not only the output stage itself, but also the picture quality**. A 100% reflection of the signal occurs when the end of the cable is either short circuited or

left open. The total (100%) energy of the signal (voltage × current) is transferred only when there is a match between the source, transmission media, and the receiver. This is why we insist that **the last element in the video signal chain should always be terminated with 75** Ω (the symbol Ω stands for ohms).

In CCTV, 75 Ω is taken as a characteristic impedance for all the equipment producing or receiving video signals. This is why the coaxial cable is meant to be used with 75 Ω impedance. This does not exclude manufacturers producing, say, 50 Ω equipment (which used to be the case with some broadcast or RF equipment), but then impedance converters (passive or active) need to be used between such sources and 75 Ω recipients.

Impedance matching is also done with the twisted pair transmitters and receivers, which will be discussed later in this chapter.

The 75 Ω of the coax **is a complex impedance, defined by the voltage/current ratio at each point of the cable. It is not a pure resistance, and therefore it cannot be measured with an ordinary multimeter.**

To calculate the characteristic impedance, we will make use of the electromagnetic theory as mentioned earlier and we will represent the cable with its equivalent network, composed of R, L, C, and G per unit length. This network, as shown on the schematic diagram previously, has an impedance of:

$$Zc = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \qquad (48)$$

where, as already explained, R is the resistance, L is the inductance, G is the conductance, and C is the capacitance between the center core and the shield, per unit length. The symbol j represents the imaginary unit (square root of –1), which is used when representing complex impedance, $\omega = 2\pi f$, where f is the frequency.

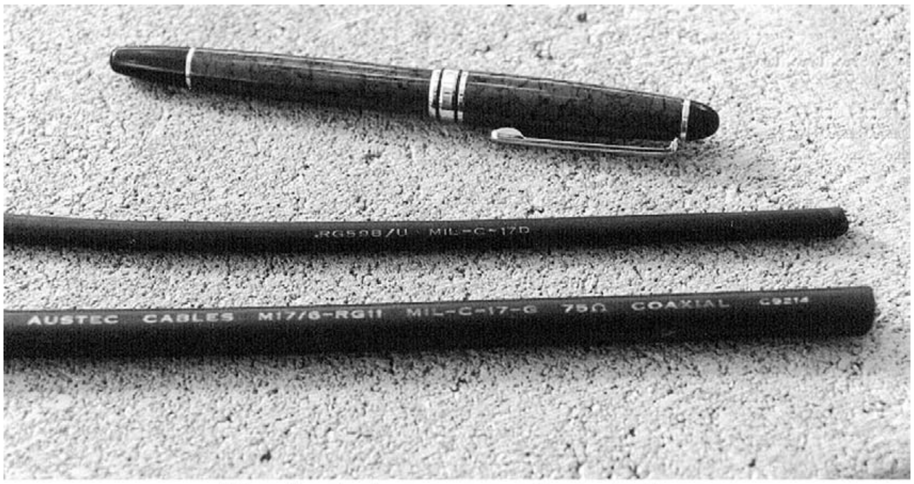
If the coaxial cable is of a reasonably short length (less than a couple of hundred metres), R and G can be ignored, which brings us to the simplified formula for the coax impedance:

$$Zc = \sqrt{\frac{L}{C}} \qquad (49)$$

This formula simply means that the **characteristic impedance does not depend on the cable length and frequency but on the capacitance and inductance per unit length**. This is not true, however, when the length of a cable like RG-59/U exceeds a couple of hundred meters. The resistance and the capacitance then become significant, and they **do affect** the video signal. **For reasonably short lengths, however, the above approximation is pretty good.**

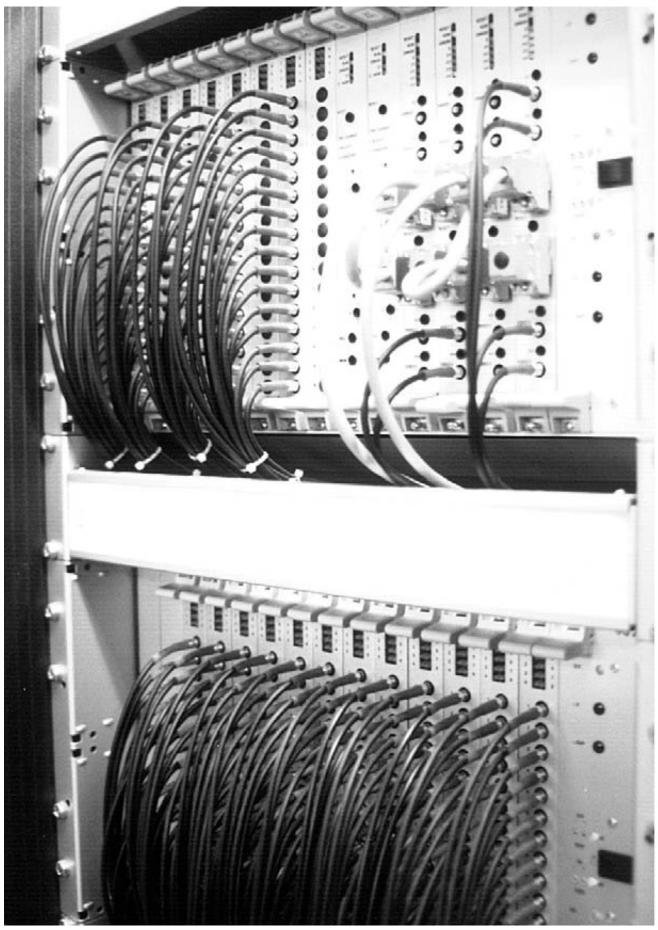
The cable limitations we have are mainly a result of the accumulated resistance and capacitance, which are so high that the approximation (49) is no longer valid and the signal is distorted considerably. This is basically in the form of voltage drop, high-frequency loss, and group delay.

The most commonly used coaxial cable in CCTV is the RG-59/U, which can successfully and without in-line correctors, transfer B/W signals up to 300 m and color up to 200 m.



Physical size comparison between RG-59 and RG-11 coax

The other popular cable is the RG-11/U, which is thicker and more expensive. Its maximum recommended lengths are up to 600 m for a B/W signal and 400 m for a color signal. There are also thinner coaxial cables with 75 Ω impedance, with only 2.5 mm diameter or even coax ribbon cables. They are very practical for crowded areas with many video signals, such as matrix switchers with many inputs. Their maximum cable run is much shorter than the thicker representatives, but sufficient for links and patches. Note that these numbers may vary with different manufacturers and signal quality expectations.



Miniature coaxial cable can save a lot of space and improve accessibility.

The difference between the B/W and color signal maximum run is due to the color subcarrier of 4.43 MHz for PAL or 3.58 for NTSC. Since a long coaxial cable acts as a low-pass filter, the color information will obviously be affected sooner than the lower frequencies, so the loss of color information will happen before the loss of details in the lower frequencies.

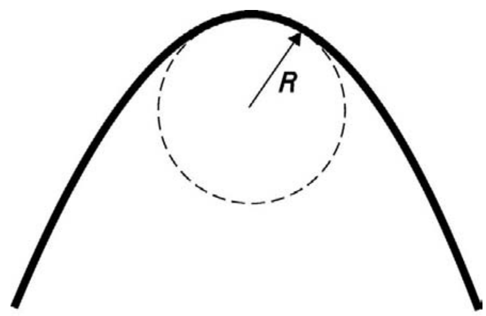
If longer runs are required, additional devices can be used to equalize and amplify the video spectrum. Such devices are known as **in-line amplifiers**, **cable equalizers, or cable correctors**. Depending on the amplifier (and cable) quality, double or even triple lengths are possible.

In-line amplifiers are best if they are used in the middle of the cable run because of the more acceptable S/N ratio, but this is quite often impossible or impractical due to the need for power supply and storage. So, the majority of in-line amplifiers available in CCTV are designed

to be used at the camera end, in which case we actually have ***pre-equalization*** and ***pre-amplification*** of the video signal. There are, however, devices that are used at the monitor end, and they have $1V_{pp}$ output with ***post-equalization*** of the video bandwidth.

Starting from the above theoretical explanation of the impedance, it can be seen that the cable uniformity along its length is of great importance for fulfilling the characteristic impedance requirements. **The cable quality depends on the precision and uniformity of the center core, the dielectric, and the shield. These factors define the C and L values of the cable, per unit length. This is why careful attention should be paid to the running of the cable itself and its termination.** Sharp loops and bends affect the cable uniformity and consequently the cable impedance. This results in high-frequency losses (i.e., fine picture detail loss), as well as double images due to signal reflections. So, if a short and good-quality cable is improperly run, with sharp bends and kicks, the picture quality will still be far from perfect.

Bends no smaller than 10 times the diameter of the coax are suggested for best performance. This is the equivalent of saying "*bending radius should not be smaller than 5 times the diameter, or 10 times the radius of the cable*." This means an RG-59/U cable should not be bent in a loop with a diameter smaller than 6 cm (2.5"), and an RG-11/U should not be bent in a loop smaller than 10 cm (4") in diameter.



Minimum bending radius

Copper is one of the best conductors for a coaxial cable. Only gold and silver will show a better performance (resistance, corrosion), but these are too expensive to be used for cable manufacturing. A lot of people believe that copper-plated steel makes a better cable, but this is not correct. Copper-plated steel can only be cheaper and perhaps stiffer, but for longer lengths, in CCTV, copper would be the better choice. Copper-plated steel coaxial cables are acceptable for master antenna (MATV) installations, where the transmitted signals are RF modulated (VHF or UHF). Namely, with higher frequencies the so-called skin effect becomes more apparent where the actual signal escapes on the copper-plated surface of the conductor (not the shield, but the center conductor). CCTV signals are, as explained, in the basic bandwidth, and this is why a copper-plated steel coaxial cable might be okay for RF signals but not necessarily for CCTV. So one should always look for a copper coaxial cable.

BNC connectors

A widely accepted coaxial cable termination, in CCTV, is the BNC termination. BNC stands for ***Bayonet-Neil-Concelman*** connector, named after its designers. There are three types: screwing, soldering, and crimping.


BNC connector

Crimping BNCs are proven to be the most reliable of all. They require specialized and expensive stripping and crimping tools, but it pays to have them. Of the many installations done in the

industry, **more than 50% of problems are proven to be a result of bad or incorrect termination**. An installer does not have to know or understand all the equipment used in a system (which will be commissioned by the designer or the supplier), but if he or she does proper cable runs and terminations, it is almost certain that the system will perform at its best.



Male and female crimping BNC elements

There are various BNC products available on the market, of which the male plug is the most common. Female plugs are also available, as well as right angle adaptors, BNC-to-BNC adaptors (often called "barrels"), 75 Ω terminators (or "dummy loads"), BNC-to-other-type of video connection, and so on.

Breaking the cable in the middle of its length and terminating it will contribute to some losses of the signal, especially if the termination and/or BNCs are of a bad quality. A good termination can result in as small as 0.3 to 0.5 dB losses. If there are not too many of them in one cable run, this is an insignificant loss.



Various BNC connectors and adaptors

There are silver-plated and even gold-plated BNC connectors designed to minimize the contact resistance and protect the connector from oxidation, which is especially critical near the coast (salt water and air) or heavily industrialized areas.

A good BNC connector kit should include a gold-plated or silver-plated center tip, a BNC shell body, a ring for crimping the shield, and a rubber sleeve (sometimes called a "strain relief boot") to protect the connector's end from sharp bends and oxidation.

Coaxial cables and proper BNC termination

Never terminate a coaxial cable with electrical cutters or pliers. Stripping the coaxial cable to the required length using electrical cutters is very risky. First, small pieces of copper fall around the center core, and one can never be sure that a short circuit will not occur. Also, the impedance changes even if they do not short circuit the core and the shield. Second, using normal pliers for fixing the BNC to the coaxial cable is never reliable. All in all, these are very risky tools to terminate crimping BNCs, and they should only be used when no other tools are available (remember to always take utmost care

when using them).

If you are an installer, or a CCTV technician who regularly terminates coaxial cables, get yourself a proper set of tools. These are precise cutters, a stripping tool, and a crimping tool.

Make sure you have the crimping and stripping tools for the right cable. If you are using RG-59/U (overall diameter 6.15 mm) do not get it confused with RG-58/U (overall diameter 5 mm) even though they look similar. For starters, they have a different impedance, i.e., RG-59/U is 75 Ω, compared to RG-58/U which is 50 Ω. Next, RG-59/U is slightly thicker, both in the center core and the shield. There are BNC connectors for the RG-58/U which look identical externally, but they are thinner on the inside.

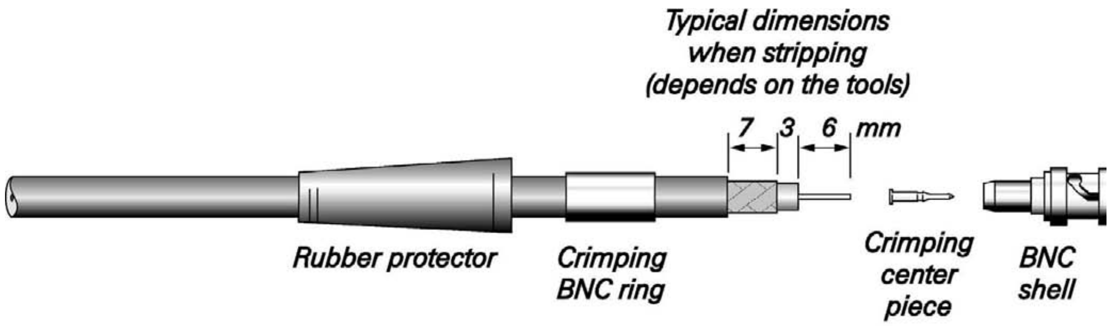
The best thing to do is to waste one and try terminating it before proceeding with the installation. Sometimes a small difference in the cable's dimensions, even if it is RG-59/U, may cause a lot of problems fitting the connectors properly.



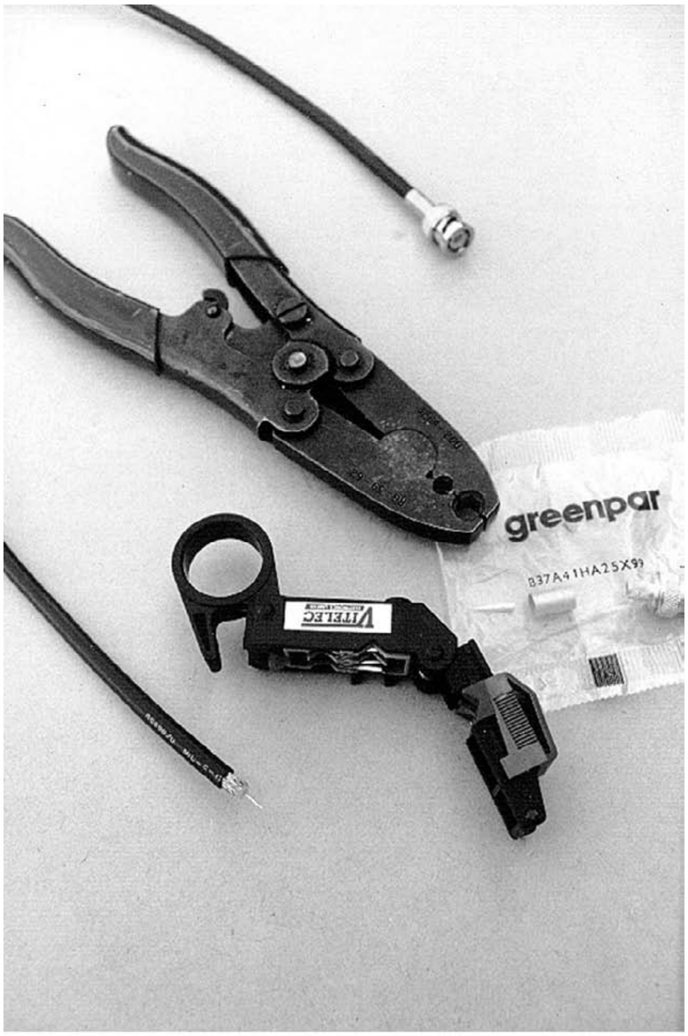
Samples of bad BNC terminations

Technically, a solid center core coaxial cable is better, both from the impedance point of view (the cable is stiffer and preserves the "straightness") and from the termination point of view. Namely, when terminating the solid core cable, it is easier to crimp the center tip, compared to the stranded core cable which is too flexible. Some people may prefer a stranded center core coax, mainly because of its flexibility, in which case care should be taken when terminating as it is very easy to short circuit the center core and the shield because of its flexibility.

If there are no other tools available, it is best to get the soldering-type BNC connectors and to terminate the cable by soldering. Care should be taken with the soldering iron's temperature, as well as the quality of the soldering, since it can easily damage the insulation and affect the impedance. In this instance, a multistranded core coax would be better.



Suggestions for a correct BNC termination (dimensions depend on stripping tool)



Tools for good termination

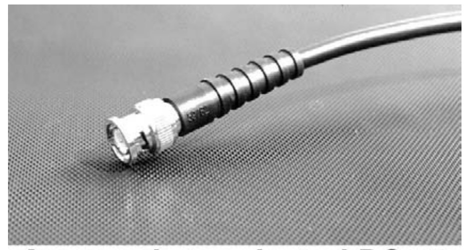
If you have a choice of crimping connectors, look for the ones that are likely to last longer in respect to physical use and corrosion, like silver-plated or gold-plated BNCs. A good practice would be to use “rubber sleeves” (sometimes called “protective sleeves”) for further protection of the interior of the BNC from corrosion and to minimize bending stress from plugging and unplugging.

In special cases, as with pan/tilt domes, there might be a need for a very thin and flexible 75 Ω coaxial cable (due to constant panning and tilting of the camera). Such cables are available from specialized cable manufacturers, but do not forget that you need special BNCs and tools for them.

Even if such a cable could be as thin as 2.5 mm, as is the case with the RG-179 B/U cable, the impedance would still be 75 Ω, which is achieved by the special dielectric and center core thickness. The attenuation of such a cable is high, but when used in short runs it is negligible.

For installations where much longer runs are needed, other 75 Ω cables are used, such as RG-11B/U with an overall diameter of more than 9 mm. Needless to say, an RG-11 cable also needs special tools and BNCs for termination. Some installers use machines purposely built to strip or label coaxial cables. Although these machines are expensive and hard to find, they do exist and if you are involved in very large installations they are a worthwhile investment.

Coaxial cable	Impedance (Ω)	Overall diameter (mm)	Typical attenuation @10 MHz (dB/100 m)
RG-179B/U	75	2.5	17.4
RG-59B/U	75	6.15	3.3
RG-6B/U	75	6	2.2
RG-11B/U	75	10	1.3


A properly terminated RG-59 coaxial cable

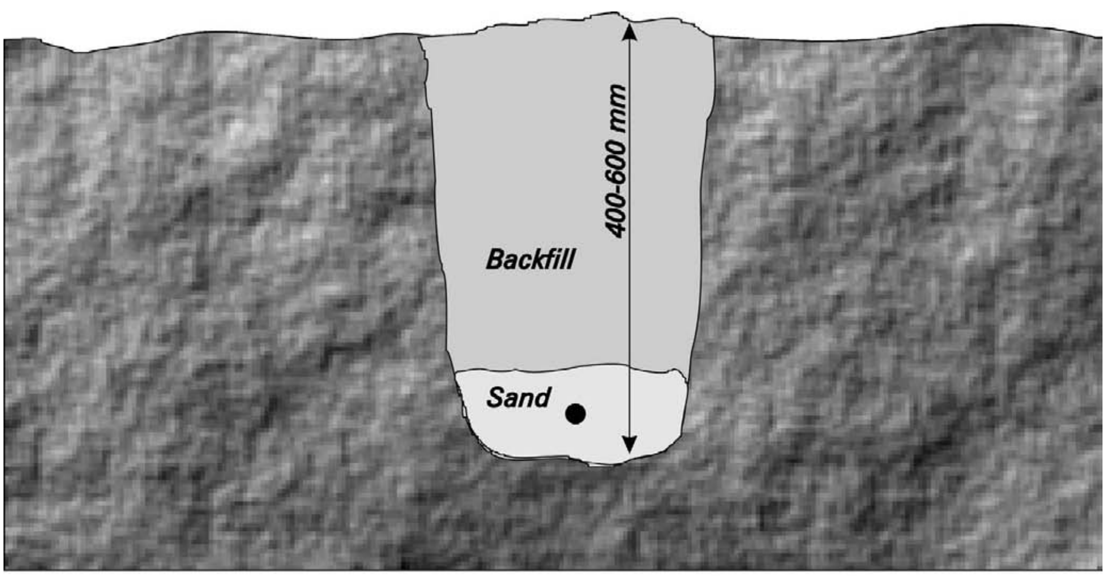
In the accompanying table below, typical attenuation figures are shown for various coax cables. Please note that the attenuation is shown in decibels and that it refers to the voltage amplitude of the video signal. If we use the decibel table shown under the section of S/N for cameras, it can be worked out that 10 dB is equivalent to attenuation of the signal to 30%, that is, 0.3 V_{PP}. The RG-59 will attenuate the signal for 10 dB after 300 m. Such low-signal amplitude may be insufficient for a monitor or VCR to lock onto. This is the point of attenuation where we would usually require an amplifier to boost the signal.

Installation techniques

Prior to installation, it should be checked what cable length can be obtained from the supplier. Rolls of approximately 300 m (1000 ft) are common, but 100 m and 500 m can also be found. Naturally, it is better to run the cable in one piece whenever possible. If for some reason the installers need a longer run than what they have, the cable can be extended by terminating both the installed and the extension cable. In such a case, although it is common practice to have a BNC plug connected to another BNC plug with a so-called ***barrel adaptor***, it is better to minimize joining points by using one BNC plug and one socket (i.e., “male” and “female” crimping BNCs).

Before cable laying commences, the route should be inspected for possible problems such as feed-through, sharp corners, and clogged ducts. Once a viable route has been established, the cable lengths should be arranged so that any joints, or possible in-line amplifier installation, will occur at accessible positions.

At the location of a joint it is important to leave an adequate overlap of the cables so that sufficient material is available for the termination operation. Generally, the overlap required does not need to be more than 1 m.



Trenching and burying recommendations

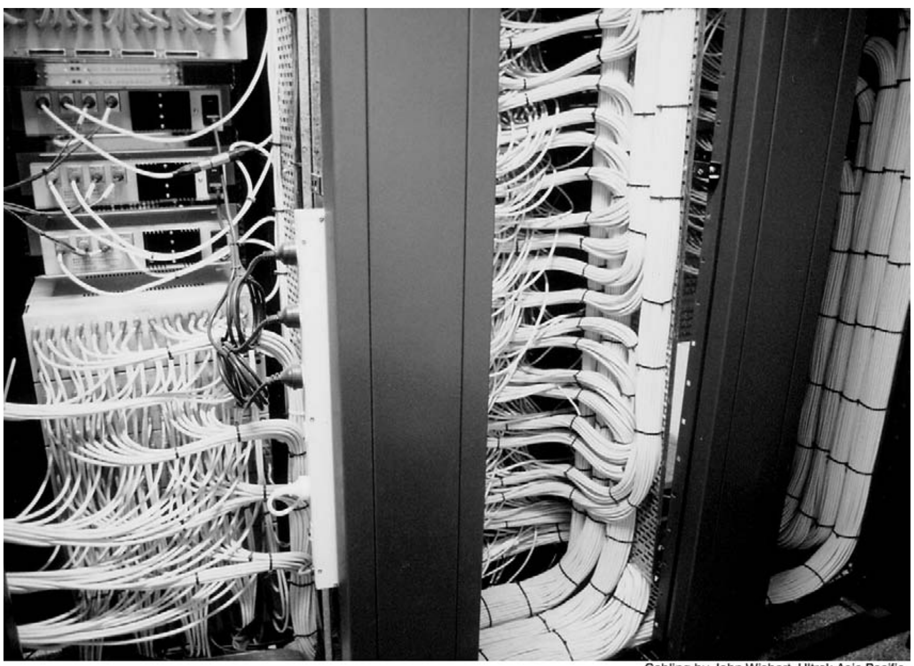
Whenever possible, the cable should be run inside a conduit of an adequate size. Conduits are available in various lengths and diameters, depending on the number of cables and their diameters. For external cable runs, a special conduit with better UV protection is needed. In special environments, such as railway stations, special metal conduits need to be used. These are required because of the extremely high electromagnetic radiation that occurs when electric trains pass.

Similar treatment should be applied when a coaxial cable is run underground. When burying a cable, foremost consideration should be given to the prevention of damage due to excessive local loading points. Such loading may occur when backfill material or an uneven trench profile digs into the cable. The damage may not be obvious instantly but the picture will get distorted due to the impedance change at the point of the cable's distortion. No matter what, the cost of digging up the cable and repairing it makes the expenditure of extra effort during laying well worthwhile.


Courtesy of Pacific Communications

Automatic coax cable-stripping machine

The best protection against cable damage is laying the cable on a bed of sand approximately 50 to 150 mm deep and backfilling with another 50 to 150 mm of sand. Due care needs to be exercised in the cutting of the trench so that the bottom of the trench is fairly even and free of protrusions. Similarly, when backfilling, do not allow soil with a high rock content to fall unchecked onto the sand and possibly put a rock through the cable, unless your conduit is extremely tough.

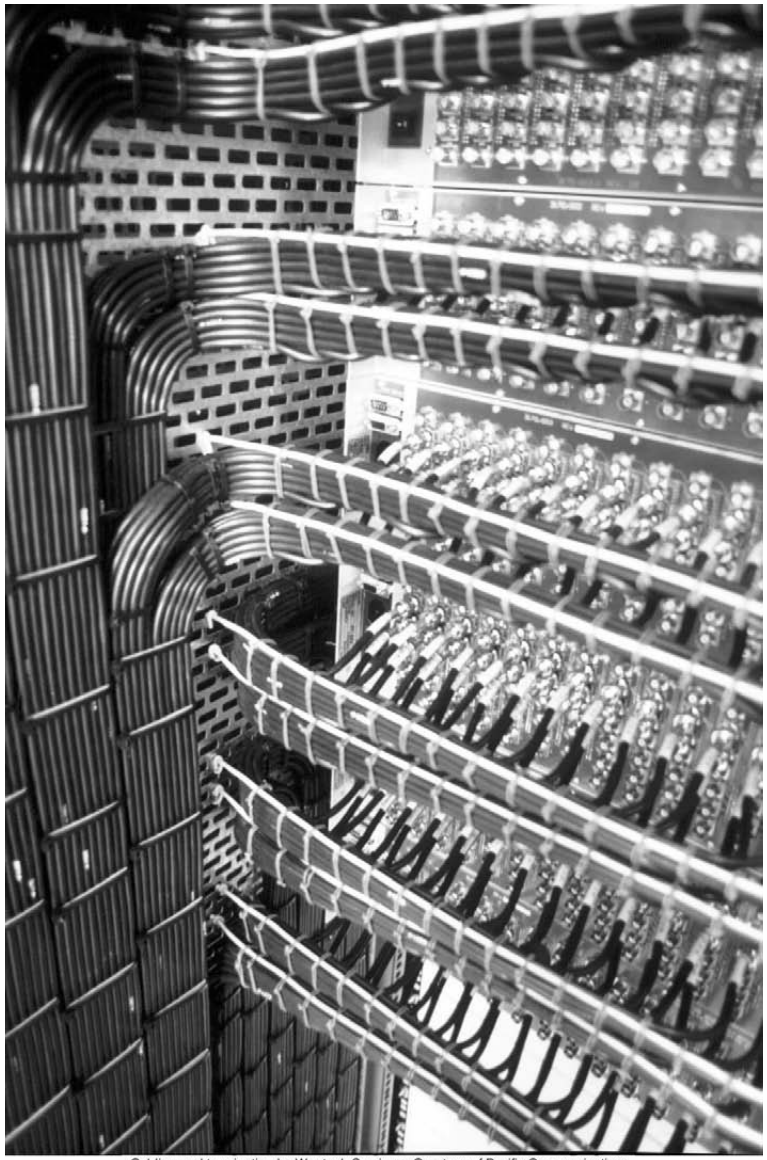

Cabling by John Wishart, Ultrak Asia Pacific

It takes a lot of time and labor to have thousands of cables neatly organized and labeled.

The trench depth is dependent on the type of ground being traversed as well as the load that is expected to be applied

to the ground above the cable. A cable in solid rock may need a trench of only 300 mm or so, whereas a trench in soft soil crossing a road should be taken down to about 1 m. A general-purpose trench, in undemanding situations, should be 400 to 600 mm deep with 100 to 300 mm total sand bedding.

Placing a coaxial cable on cable trays and bending it around corners requires observing the same major rule: **minimum bending radius.** As mentioned, the minimum bending radius depends on the coaxial cable size, but the general rule is that **the bending radius should not be smaller than 5 times the diameter of the cable (or 10 times the radius)**. The minimum bending radius must be observed even when the cable tray does not facilitate this. The tendency to keep it neat and bend the coaxial cable to match power and data cables on the tray must be avoided. Remember, bending coax more than the minimum bending radius affects the impedance of the cable and causes a video signal quality loss.



Cabling and termination by Wegtech Services. Courtesy of Pacific Communications.

A brilliant example of very neat cabling practices

The pulling of coaxial cables through ducts is performed by using a steel or plastic leader and then joining and securing all the cables that need to go through. Some new, tough plastic materials, called "snakes," are becoming more popular.

The types of cable ties normally used to tie the cables together are generally satisfactory, but remember, excessive force should not be applied, as it squashes the coax and therefore changes the impedance again.

Should a particular duct require the use of a lubricant, it is best to obtain a recommendation from the cable manufacturer. Talcum powder and bean-bag-type polystyrene beans can also be quite useful in reducing friction.

In some conditions the cable may already be terminated by connectors. These must be heavily protected while drawing the cable. The holes in such a case need to be bigger.


Courtesy of Pacom
Automatic coax labeling machine

Between the secured points of a cable it is wise to allow a little slack rather than leaving a tightly stretched length that may respond poorly to temperature variations or vibration.

If the cable is in some way damaged during installation, then leave enough extra cable length around the damaged area so that additional BNC joiners can be inserted.

Time domain reflectometer (TDR)

When a complex and long coaxial cable installation is in question, it would be very useful to get a time domain reflectometer to help determine the location of bad cable spots.

The TDR works on a basic principle in that it inserts short and strong pulses and measures the reflected energy. By determining the delay between the injected and the reflected signals, a pretty accurate localization of bad termination points and/or sharp bends can be made. This can be especially important if the cable goes through inaccessible places.

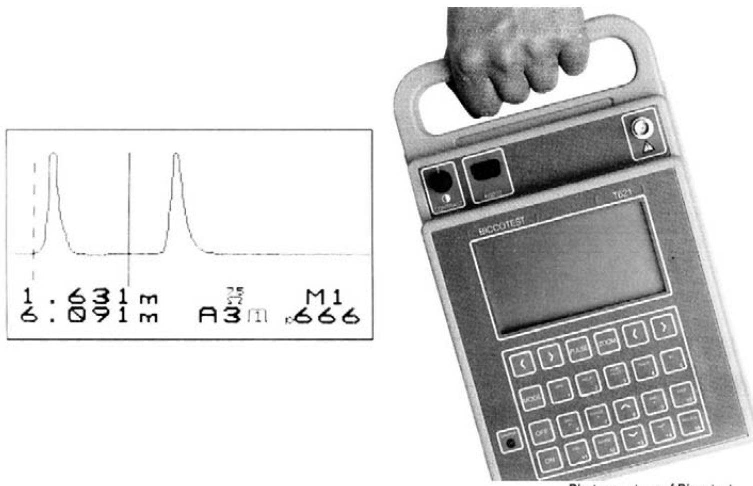


Photo courtesy of Biccotest
Time domain reflectometer

Twisted pair video transmission

Twisted pair cable is an alternative to the coaxial cable. It is useful in situations where runs longer than a couple of hundred meters have to be made. It is especially beneficial when only two wires have already been installed between two points.

Twisted pair cable is reasonably cheap when used with normal wires, but if a proper cable (as per the recommendations by the manufacturers) is used, with at least 10 to 20 twists per meter and with shielding, the price becomes much higher.

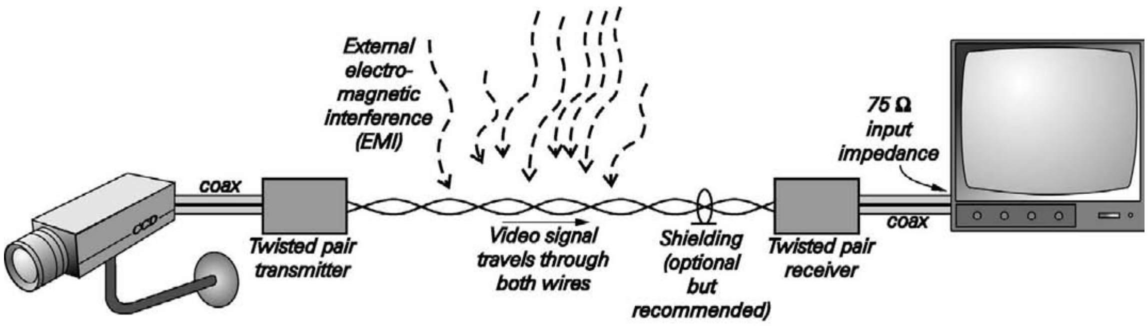
Twisted pair transmission is also called **balanced video transmission**.

The idea behind this is very simple and different to the unbalanced (coaxial) video transmission. Namely, to minimize the external electromagnetic interference, the twisted pair trick is to have a signal converted

into balanced mode and sent via twisted wires. All the unwanted electromagnetic interference and noise will eventually induce an equal amount of current in both of these wires. This is why we need a proper twisted pair – the idea is to have **both of the wires equally exposed to the interference** and the voltage drop. Unlike the coaxial transmission, where the shield is grounded and commons the zero potential between the two points, **the twisted pair video transmission concept does not common the zero potential between the end points**. So when the signal arrives at the twisted pair receiver end, it first comes to a differential amplifier input, with a well-balanced and good common mode rejection ratio (CMRR) factor. This differential amplifier reads the **differential signal between the two wires**.

If the two wires have similar characteristics and enough twists per meter (the more the better), they will be **equally affected** by noise, voltage drops and induced signals. With a good CMRR amplifier at the receiver end, most of the unwanted noise will be eliminated.

The output impedance of the twisted pair transmitters is usually 100 Ω.

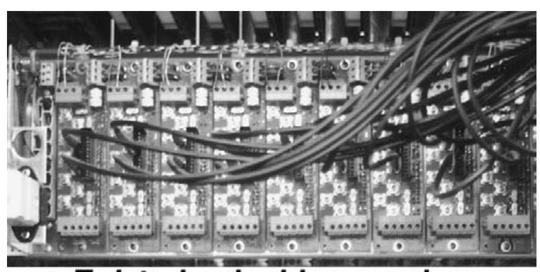


Balanced (twisted pair) video transmission

The drawback of this type of transmission is that one transmitting and one receiving unit are necessary in addition to the cable. They increase not only the cost of the system but also the risk of having the signal lost if either of the two components fails. Quality, however, is on the increase, and price is dropping.

If the correct cable is used, much longer distances can be achieved than what is possible with an RG-59 or even an RG-11 cable. Manufacturers usually quote over 2000 m for B/W signals and more than 1000 m for color, without any in-line repeaters. Furthermore, when balanced transmission is used, no ground loops are apparent as with coax. Termination of the twisted pair cable does not require special tools and connectors. All these facts make such transmission even more attractive.

I have always preferred coax installation. But after seeing a major installation at the Frankfurt airport done with twisted pair video, I found the signal quality was, to my surprise, as good as with coax. I am now convinced that with proper equipment selection, both cable and transmitter/receiver pair, this might be a good alternative to coax. In fact, I have seen even more installation in the last five years being done with twisted pair, which is especially practical with DVRs, as a majority of them are extremely sensitive to ground loops.



Twisted pair video receiver modules in a 19" rack

Microwave links

Microwave links are used for good-quality wireless video transmission.

The video signal is first modulated with a frequency that belongs in the microwave region of the electromagnetic spectrum. **The wavelengths of this region are between 1 mm and 1 m**. Using the known equation between wavelength (λ) and the frequency (f) :

$$\lambda = c / f \qquad [\mathrm{m}] \qquad (50)$$

where c is the speed of light 300,000,000 m/s, we can find out that the microwave region is between 300 MHz and 30 GHz. The upper region actually overlaps with the infrared frequencies that are defined as up to 100 GHz. Therefore, the lower part of the infrared frequency spectrum is also in the microwave region. In practice, however, the typical frequencies used for microwave video transmission are between 1 GHz and 10 GHz.



Microwave wireless video transmission

Since many services, such as the military, the police, ambulances, couriers, and aircraft radars use artificial frequencies, there is a need for some regulation of frequency. This is done on an international level by the International Communications Union (ITU) and by the local authorities in your respective country. For Australia this was the Department of Transport and Communications, which was recently renamed the ***Spectrum Management Agency***. Thus, a very important fact to consider when using microwave links in CCTV is that each frequency and microwave power needs to be approved by the local authority in order to minimize interference with the other services using the same spectrum. This is to protect the registered users from new frequencies, but it is also a downfall (at least in CCTV) for using microwaves and one of the reasons why a lot of CCTV designers turn to microwaves only as a last resort.

Microwave links transmit a very wide bandwidth of video signals as well as other data if necessary (including audio and/or PTZ control). The transmission bandwidth depends on the manufacturer's model. For a well-built unit, a 7 MHz bandwidth is typical and sufficient to send high-quality video signals without any visible degradation.



Photo courtesy of Mitec

Microwave antennas and Tx/Rx modules

Microwaves are usually ***unidirectional*** when a CCTV video signal is sent from point A to point B, but they can also be ***bidirectional*** when a video signal needs to be sent in both directions, or video in one and data in the other. The latter is very important if PTZ cameras are to be controlled.

The encoding technique in video transmission is usually frequency modulation (FM), but amplitude modulation (AM) can also be used. If audio and video are transmitted simultaneously, usually the video signal is AM modulated and the audio FM, as is the case with broadcast TV signals.

A line of sight is needed between the transmitter and the receiver. In most cases, the transmitting and receiving antennas are parabolic dishes, similar to those used for satellite TV reception.

The distances achievable with this technology depend on the transmitter output power and on the diameter of the antenna that contributes to the gain of the transmitter and the sensitivity of the receiver.

Obviously, atmospheric conditions will affect the signal quality. The same microwave link that has an excellent picture during a nice day may have considerable signal loss in heavy rain if it is not designed properly. Fog and snow also affect the signal. If the parabolic antenna is not anchored properly, wind may affect the links indirectly by shaking it, causing an intermittent loss of line of sight.

Many parabolic antennas come with a plastic or leather cover that protects the actual inner parabola. This protector simultaneously breaks the wind force and protects the sensitive parts from rain and snow.



Microwave transmitter

The fitting and stability of a microwave antenna are of paramount importance to the links. The longer the distance that is required, the bigger the antenna and more secure fittings that are required. The initial line-of-sight alignment is harder to achieve for longer distances, although better quality units have a field strength indicator built in, which helps to make the alignment easier.

Maximum achievable transmitting distances of up to 30 km are quoted by most specialized manufacturers. In most cases a typical CCTV application will require only a couple of hundred meters, which is often not a problem as long as there is a line of sight.

The transmitting power and the size of the antenna required for a specific distance need to be confirmed with the manufacturer.

For shorter distances, microwave links may use rod or other types of nonparabolic antennas, which become very practical if dimensions are in question. The obvious security problem in such a case would be the omnidirectional radiation of the signal, but the advantage would be a fairly wide area of coverage.

One very interesting application that was initially developed in Australia was to use an omnidirectional microwave with a transmitting antenna fitted on top of a race car roof, which would send signals to a helicopter above the race track. From there it would be redirected to a TV broadcast van. With such a setup, the so-called Race Cam allowed the television audience to see the driver's view.

Most microwave manufacturers have RS-232 links available for camera and other remote control data, but also have in mind that some CCTV manufacturers offer their controls in audio bandwidth, so you

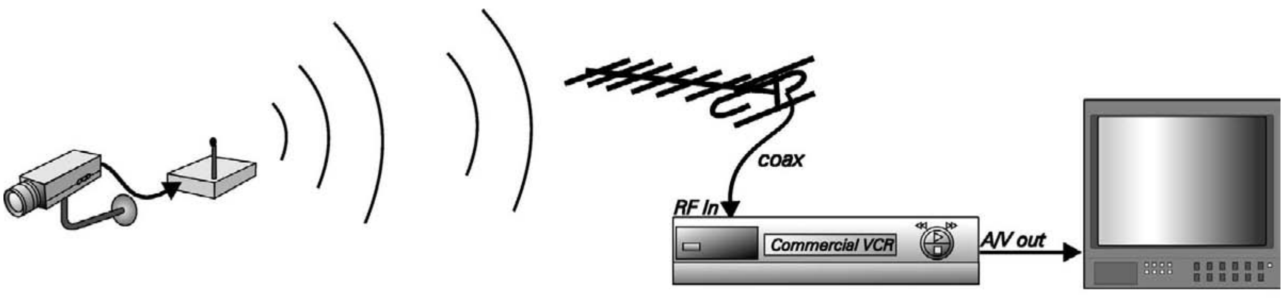
can actually use an audio channel of the microwave (in the opposite direction of the video signal) to control PTZ cameras.

Lately, with the introduction of digital video and networking, an increased number of “digital microwaves” are establishing basically a network link between two points. That way, a digital video system can easily become interlinked by simply assigning to it an IP address. The most popular “free to use” frequency is 2.4 GHz, and here too, as in the analog microwave links, the maximum distance achievable depends on the link power and the antenna size.

RF wireless (open air) video transmission

RF video transmission is similar to the microwave transmission in the way the modulation of signals is done. The major differences, however, are the modulation frequency in the VHF or UHF bands and the transmission of the signal, which is usually omnidirectional. When a directional ***Yagi*** antenna is used (similar to the domestic ones used for reception of a specific channel), longer distances can be achieved and there will be less distraction to the surrounding area. It should be noted, however, that depending on the regulations of your country, the radiated power cannot be above a certain limit, after which you will require approval from your respective frequency regulatory body.

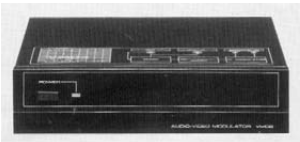
RF transmitters are usually made with video and audio inputs and the modulation techniques are similar to those of the microwaves: video is AM modulated and audio is FM. The spectrum transmitted depends on the make, but generally it is narrower than the microwave. This usually means 5.6 MHz, which is sufficient to have audio and video mixed into one signal.



Wireless (RF) video transmission

Consumer products with similar characteristics to those listed above are found in the so-called RF senders, or wireless VCR links. The RF modulator is fed with the audio and video signals of the VCR outputs and re-modulates and then transmits them so they can be picked up by another VCR in the house. Devices like these are not made with CCTV in mind, so the distances achievable are in the vicinity of a household area. Sometimes this might be a cheap and easy way out of a situation where a short-distance wireless transmission is required.

Since VHF and UHF bands are for normal broadcast TV reception, you should check with your local authority and use channels that do not interfere with the existing broadcasting. In most countries, UHF channels 36 to 39 are deliberately not used by the TV stations because they are left for VCR-to-TV conversion, video games, and similar uses.


An RF modulator

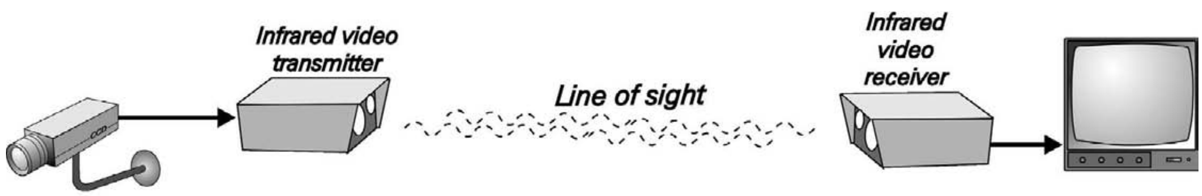
The downfall of such an RF CCTV transmission is that any TV receiver at a reasonable distance can pick the signal up. Sometimes, however, this might be exactly what is wanted. This includes systems in big building complexes, where the main entrance cameras are injected through the MATV system so that the tenants can call the camera on a particular channel of their TV receivers.

The RF frequency is such that, when compared to the microwave links, it does not require line of sight, as the RF (depending upon whether it is UHF or VHF) can penetrate through brick walls, wood, and other nonmetal objects. How far one can go with this depends on many factors, and the best bet is to test it out in the particular environment (in which the RF transmitter will be used).

Infrared wireless (open air) video transmission

As the heading suggests, an infrared open air video transmission uses optical means to transmit a video signal. An infrared LED is used as a light carrier. The light carrier is **intensity modulated with a video signal**. Effectively, this type of transmission looks like a hybrid between microwave and fiber optics transmission (to be discussed a little bit later). Instead of the microwave frequencies being used, it is the infrared that are used (infrared frequencies are higher). And instead of sending such light modulation over a fiber optics cable (such is the case in fiber optics, using the principles of total reflection), open space is used. **We therefore have to have line of sight.** The obvious advantage of the infrared light radiation is that you do not need a special license.

In order to have the infrared light concentrated into a narrow beam to minimize dispersion light losses, a lens assembly is required at the transmitter end to concentrate the light into a narrow beam and a lens assembly at the receiver end to concentrate the light onto the photosensitive detector.



Infrared (wireless) video transmission

Both color and B/W, as well as audio, can be transmitted over distances of more than 1 km. Bigger lens assemblies and more powerful LEDs, as well as a more sensitive receiving end, will provide for even longer distances.

Special precautions have to be taken here for the temperature around the transmitter so that the receiver does not detect those infrared frequencies radiated by hot walls, roofs, and metal objects.

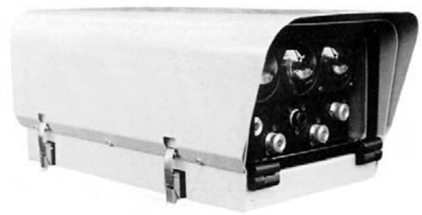

An infrared video Tx/Rx



Photo courtesy of Plettac

Infrared video transmission between trains and station cameras

Understandably, weather conditions like rain, fog, and hot wind will affect infrared links more than microwave transmission.

Transmission of images over telephone lines

First there was the "***slow-scan TV***." That was a system that would send video pictures over a telephone line at a very slow speed, usually many tens of seconds for a full-frame B/W picture. Then came up the "***fast scan***" which was a popular alternative to the "slow-scan." During the preparation of this book almost the entire CCTV industry is turning toward using the Internet as a substitute for telephone line point-to-point communication. The Internet connectivity becomes almost as good as the telephone one. Most businesses and households have, or are getting, fast Internet connection, usually using their existing telephone copper lines (this is the so called DSL) which offers a faster transmission than the "fast scan." Still, in order to be complete with this heading, and for the places without the Internet, we are going to say a few words about the typical telephone line image transmission technology in CCTV.

The slow-scan concept originates from the late 1950s, when some amateur radio operators used it. It was later applied to CCTV. The concept is very simple: There are units at both ends of the transmission path, as with any other transmission, a transmitter and a receiver. An analog video signal of a camera is captured and converted into digital format. It is then stored in the random access memory (RAM) of the slow-scan transmitter. This is usually triggered by an external alarm or upon the receiver's request. The stored image, which is at this stage in a digital format, is usually frequency modulated with an audio frequency that can be heard by the receiving phone. This frequency is usually between 1 and 2 kHz, i.e., where the phone line attenuation is lowest. When the receiver receives the signal, it reassembles the picture line by line, starting from the top left-hand corner until the picture at the receiving end is converted into an analog display (a steady picture).

This concept was initially very slow, but considering the unlimited distances offered by telephone lines (provided there was a transmitter compatible with the receiver), it was an attractive concept for remote CCTV monitoring.

The slow-scan transmitter would usually have more cameras attached to it, so the viewer could browse

through all of them. Also, any camera could send an image automatically when triggered by an external alarm associated with it. More transmitters could thus report to one or more receiving stations, each one protected by a password to eliminate unwanted listeners.

One way of increasing the speed of transmission was to reduce the digitized picture resolution or to use only a quarter of the screen for each camera. So the initial 32 seconds could effectively be reduced to 8 seconds for when one picture update was required, or perhaps, have a 32-second update of a quad screen with blocks of four cameras. Considering that other signals could be added to this, like audio or control signals for remote relay activation, a better picture can be attained for these historic beginnings.

Older-generation slow scan systems would take 32 seconds to send a single low-quality picture from an alarmed site to the monitoring station. Dial-up and connecting time should be added to this, totaling to more than a minute for the completion of the first image transmission. The slow-scan, however, was very popular and ahead of its time. Today we have much more advanced techniques when video signals need to be transmitted over the telephone line.



Photo courtesy of Vision Systems

Fast-scan transmitter and receiver unit

The new technology, using the same concept but much faster image processing and compression algorithms, is called ***Fast Scan*** and can achieve speeds of less than 1 s for a full-color picture update. The image manipulation is digital and various compression techniques are used to even further increase the transmission speed, yet preserving the image quality.

The most important details to take into consideration when choosing a fast-scan system are:

- The framestore resolution (in pixels)
- B/W or color
- Whether other signals can be transmitted simultaneously (often PTZ control is required, or perhaps some relays activation)
- The transmission speed

For the last consideration you have to be very flexible because different telephone lines and different modems will give different and unfair comparisons.

For the customer it is sometimes more important just to see very roughly what is happening at the other end of the line, as long as it is fast. Other customers may require a good definition (resolution), regardless of the time delay.

It is also important to know what else can be connected to the system in the future. Is there a need for

more than one camera input, or perhaps one of the cameras should have a PTZ control?

Do not forget that if you require a PTZ control, you have to accept the delay between the command issued from the keyboard and the picture update in order to see where the camera is pointing. This might be a bit unusual or unacceptable for some, but a lot of manufacturers offer intelligent updates. Namely, when a joystick is used, the picture automatically selects a smaller viewing area that remains sharp (which will have a faster update), so you can see where the camera is pointing. It then upgrades to a full screen as soon as the joystick is released.

Another type of system offers an additional integrated feature: video motion detection. The system automatically sends images as soon as activity is detected in the video signal.

PSTN

The normal PSTN (***public switched telephone network***) line has a narrow bandwidth of usually 300 to 3000 Hz, which is considered a standard (measured at 3-dBm points, where dBm is measured relative to 1 mW across 600 ohms, the telephone line impedance). Some people call this type of line plain old telephone service (POTS). PSTN is analog technology. As such, it is never constant with the bit rate it offers, as it very much depends on the noise.

Theoretically, it is impossible to send live video images of 5 MHz over such a narrow channel. It is possible, however, to compress and encode the signal to achieve faster transmission, and this can be done today by most of the fast-scan transmitters. The technological explosion of the PCs, compression algorithms, fast modems, and better telephone lines in the last few years has made it possible to transmit video images over telephone lines at rates unimaginable when the first slow-scan transmitters were developed.

As mentioned earlier, the concept remained the same as that of the slow scan, but the intelligence behind the compression schemes (what and how it transmits) has improved so much that today **a color video signal with very good resolution can be sent in less than 1 s per frame**. In addition, with many models, other control and audio signals can be sent.

The more sophisticated fast-scan systems use a method of image updating called ***conditional refresh***. After the initial image is sent, only the portion that changes needs to be resent. This allows a much more rapid update rate than that with the basic fast-scan systems. Other manufacturers stick to the full image transmission but use proprietary compression algorithms to achieve similar speeds.

In order to understand the PSTN telephone line video transmission rates, let us consider this simplified exercise:

A typical B/W video signal with 256 × 256 pixels resolution will have 256 × 256 = 65,536 bits of information, which is equal to 64 kB of digital information (65,536/1024). (Note the digital numbers $64 = 2^6$, $256 = 2^8$.)

To send this amount of uncompressed information over a telephone line using a normal 2400

bits per second modem (as was the case in the early days of slow scan), it would take about 27 s (65,536/2,400).

If the signal is compressed, however (compressions of 10, 20, or even more times are available), by say 10 times, this gets reduced to 3 s. Most fast-scan transmitters will only send the first image at this speed, after which they only send the difference in the pictures, thus dramatically reducing the subsequent images' update time to less than a second.

A color picture with the same resolution will obviously require more. A high-resolution picture of quality better than S-VHS is usually digitized in a 512 × 512 frame with 24-bit colors (8 bits of each R, G, and B) and will equal 512 × 512 × 3 = 786,432 bytes, or 768 kB. If this is compressed by 10 times, it becomes 76 kB, which is not that hard to transmit with a 14,400 bps modem at approximately 76,000/14,400 = 5 s. It all depends on the compression algorithm.



Fast-scan images can also be transmitted in quad mode for faster update.

In practice, add another few seconds to the dialing time, which is faster with DTMF (dual tone multifrequency) and slower with pulse dialing lines.

Most of the high security systems have a dedicated telephone line, which means that once the line is established, it stays open and there is no further time loss for the modem's handshake and initial picture update delay.

In the end, we should emphasize that the theoretical maximum speed of transmission that can be achieved with a POTS or PSTN line is somewhere around 56 kb/s. In practice, it is rarely over 32 kb/s, and if the telephone line is old, or far from the exchange, it could be as low as 19 kb/s.

ISDN

For the fastest possible transmission, ISDN (***Integrated Services Digital Network***) telephone lines should be used, which are available in many industrialized countries.

ISDN lines were proposed and started to be implemented in the mid-1970s, almost at the same time when CCD chips appeared.

The basic ISDN channel offers a rate of 64 kb/s, which dramatically improves the update speed of fast scan. In comparison, a normal PSTN line, as mentioned above, can go up to 14.4 kb/s when the lines are in a very good condition. Some new modems can increase this even further (up to 28.8 kb/s) by using hardware compression techniques.

The ISDN is a **digital network and transmits signals in digital format**; hence the bandwidth is not given in Hz but in b/s. For special purposes, like video conferencing and cable TV (available via telephone lines), ISDN can be used combined in ***broadband ISDN*** (B-ISDN) links, where even higher speed rates (multiples of 64 kb/s) of at least 128 kb/s can be achieved by intelligent multiplexing of more channels into one.

The unit used to connect a device to an ISDN line is usually called the ***Terminal Adaptor*** (TA); the function, as well as the appearance of such a device, is very similar to a modem with PSTN lines. Intelligent TA for B-ISDN links are also known as Aggregating Terminal Adaptors.

Do not forget, however, that in order to use the benefits of a wider ISDN, both ends (the transmitting and the receiving) need to have an ISDN connection. In most countries, ISDN connection is charged per time of use.

Cellular network

Transmitting images over mobile phones is an attractive possibility with the technology available today. A mobile phone with a modem socket, combined with a notebook computer, can easily be equipped with the software and hardware needed for wireless and mobile image transmission.

The same principles and concepts as previously discussed apply, with the exception of the transmission speed, which is much slower via the cellular network.

The digital network offers better noise immunity, although the coverage at the moment is not as good as with the analog mobile service. The digital cellular network is growing rapidly, and worldwide ROAM-ing is already possible in the majority of industrialized countries. This means that when users are overseas, they can divert their calls to the digital network in the country they are visiting and make calls without going through an operator. Understandably, to activate ROAM-ing, the user needs to inform its major carrier, although even this is becoming fully automatic.

With the digital cellular network, speed of up to 9600 kb/s can be achieved when using the modem mode. There are advancements in the hardware and software of the GSM technology where boosting data speeds from the current 9.6 kb to 14.4 kb in a single traffic channel is now possible. By multiplexing up to four channels into a single time slot, operators will be able to offer transmission rates up to 57.6 kb, six times more than is currently available and with the help of compression technology data speeds can be increased even higher.



Photo courtesy of Netcomm

A GSM modem card

Fiber optics

Fiber optics, if correctly installed and terminated, is the best quality and most secure transmission of all. Even though it has been used in long distance telecommunications, even across oceans, for over 30 years, it has been avoided or neglected in CCTV.

The main excuse installers have used was the fear of unknown technology, often labeled as “touchy and sensitive” and also considered “too expensive.”

Fiber optics, however, offers many important advantages over other media and although it used to be very expensive and complicated to terminate, it is now becoming cheaper and simpler to install.

The most important advantages of all are immunity to electromagnetic interference, more secure transmission, wider bandwidth, and much longer distances without amplification. We will, therefore, devote more space to it.

Why fiber?

Fiber optics is a technology that uses light as a carrier of information, be it analog or digital. This light is usually infrared, and the transmission medium is fiber.

Fiber optic signal transmission offers many advantages over the existing metallic links. These are:

- It provides very wide bandwidth.
- It achieves very low attenuation, on the order of 1.5 dB/km compared to over 30 dB/km for RG-59 coax (relative to 10 MHz signal).
- The fiber (which is dielectric) offers electrical (galvanic) isolation between the transmitting and receiving end; therefore, no ground loops are possible.
- Light used as a carrier of the signal travels entirely within the fiber. Therefore, it causes no interference with the adjacent wires or other optical fibers.
- The fiber is immune to nearby signals and electromagnetic interferences (EMI); therefore,



Fiber cables are very small and fragile but enclosed in tough jackets.

it is irrelevant whether the fiber optics passes next to a 110 VAC, 240 VAC, or 10,000 VAC, or whether it is close to a megawatt transmitter. Even more important, lightning cannot induce any voltage even if it hits a centimeter from the fiber cable.

• A fiber optics cable is very small and light in weight.

• It is impossible to tap into the fiber optics cable without physically intercepting the signal, in which case it would be detected at the receiving end. This is especially important for security systems.

• The cost of fiber is becoming cheaper every day. A basic fiber optics cable costs anywhere from $1 to $5 per meter, depending on the specific type and construction used.

Fiber optics also has some not so attractive features, but they are being improved:

• Termination of fiber optics requires special tools and better precision of workmanship than with any other media.

• Switching and routing of fiber optics signals are difficult.

Fiber optics offers more advantages than other cables.

Fiber optics has been used in telecommunications for many years and is becoming more popular in CCTV and security in general.

As the technology for terminating and splicing fiber improves and at the same time gets cheaper, there will be more CCTV and security systems with fiber optics.

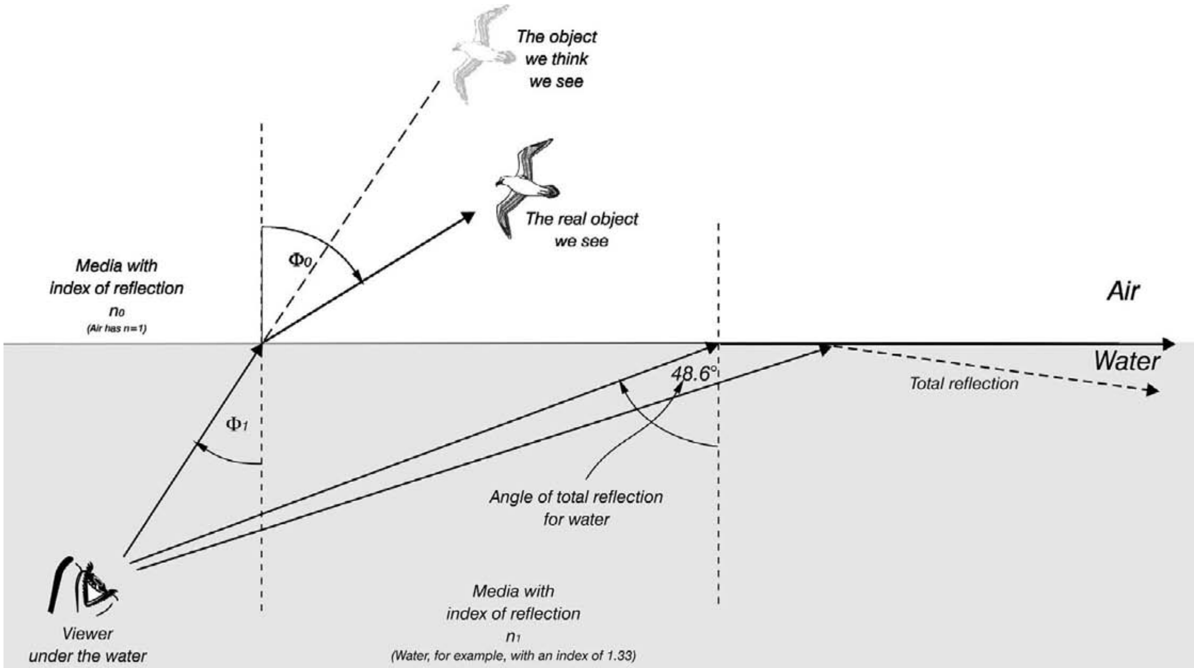
The concept

The concept of fiber optics lies in the fundamentals of light refraction and reflection.

To some it may seem impossible that a perfectly clear fiber can constrain the light rays to stay within the fiber as they travel many kilometers, and yet not have these rays exit through the walls along the trip. In order to understand this effect, we have to refresh our memory about the physical principle of total reflection.

Physicist Willebrord Snell laid down the principles of refraction and reflection in the early seventeenth century. When light enters a denser medium, not only does the speed reduce, but the direction of travel is also corrected in order for the light to preserve the wave nature of propagation (see Chapter 3). Basically, the manifestation of this is a light ray sharply bent when entering different media. We have all seen the "*broken straw effect*" in a glass of water. That is refraction.

A typical glass has an index of refraction of approximately 1.5. The higher the index, the slower the speed of light will be, thus the bigger the angle of refraction when the ray enters the surface.



Fiber optic signal transmission is based on the effect of total reflection.

The beauty of a diamond comes primarily from the rainbow of colors we see due to its high index of refraction (2.42). This is explained by the fact that a ray of light (natural light) has all the colors (wavelengths) a white light is composed of.

Fiber optics uses a special effect of refraction under a maximum incident angle; hence, it becomes a **total reflection**. This phenomenon occurs at a certain angle when a light ray **exits** from a dense medium to a sparser medium.

The accompanying drawing shows the effect of a diver viewing the sky from under the water. There is an angle below which he can no further see above the water surface. This angle is called the **angle of total reflection**. Beyond that point he will actually see the objects inside the water, and it will seem to him like looking through a mirror (assuming the water surface is perfectly still).

For the index of refraction of water (1.33), using Snell's Law, we can calculate this angle:

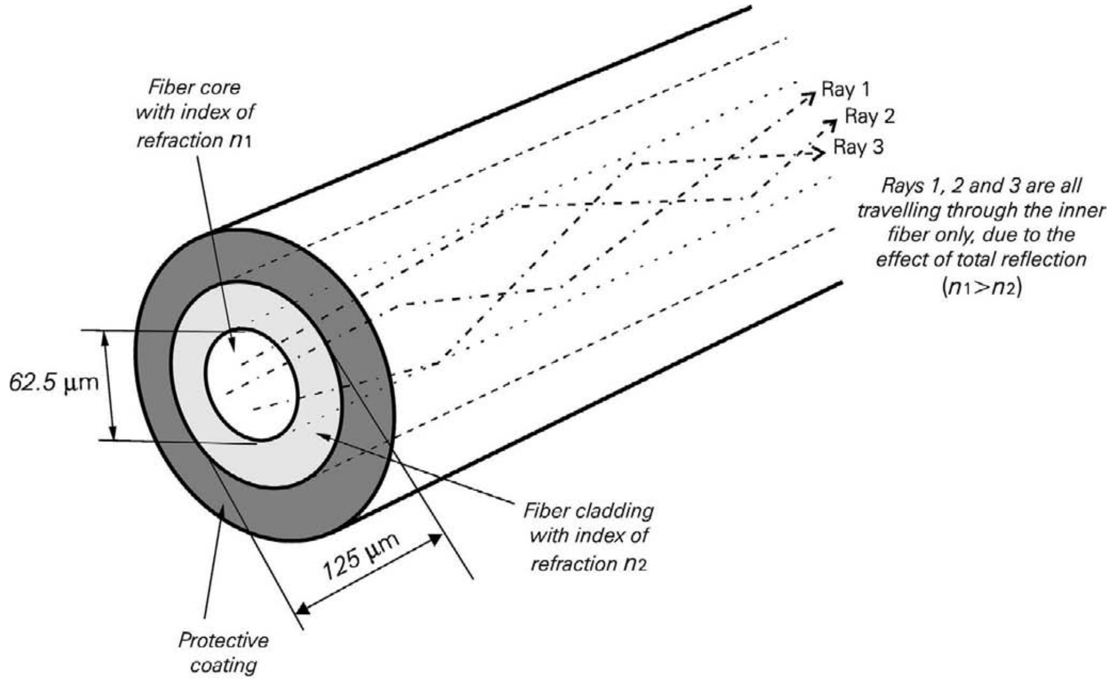
$$\sin \Phi_T = 1.00/1.33 = 0.752 \rightarrow \Phi_T = 48.6° \qquad (51)$$

The concept of fiber optics transmission follows the very same principles.

The core of a fiber optics cable has an index of refraction higher than the index of the cladding. Thus, when a light ray travels inside the core it cannot escape it because of the total reflection.

So, what we have at the fiber optics transmitting end is an LED (***light-emitting diode***) or LD (***laser diode***) that is modulated with the transmitted signal.

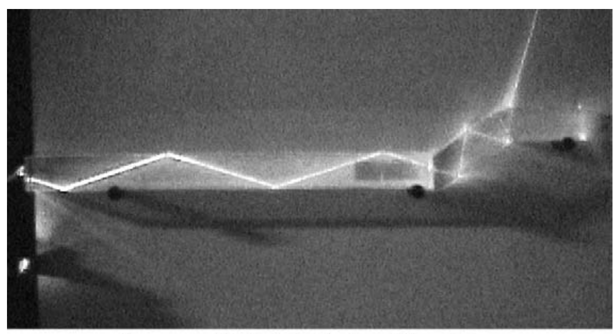
In the case of CCTV the signal will be video, but similar logic applies when the signal is digital, like a PTZ control, network, or other security data. So, when transmitting, the infrared diode is



Fiber optics usage is based on the effect of total reflection.

intensity modulated and pulsates with the signal variations. At the receiving end, we have basically a photodetector that receives the optical signal and converts it into electrical.

Fiber optics used to be very expensive and hard to terminate, but that is no longer the case, because the technology has improved substantially. Optical technology has long been known to have many potential capabilities, but major advancements are achieved when mass production of cheap fundamental devices like semiconductor light-emitting diodes, lasers, and optical fibers are made.



Laser light total reflection inside a fiber channel

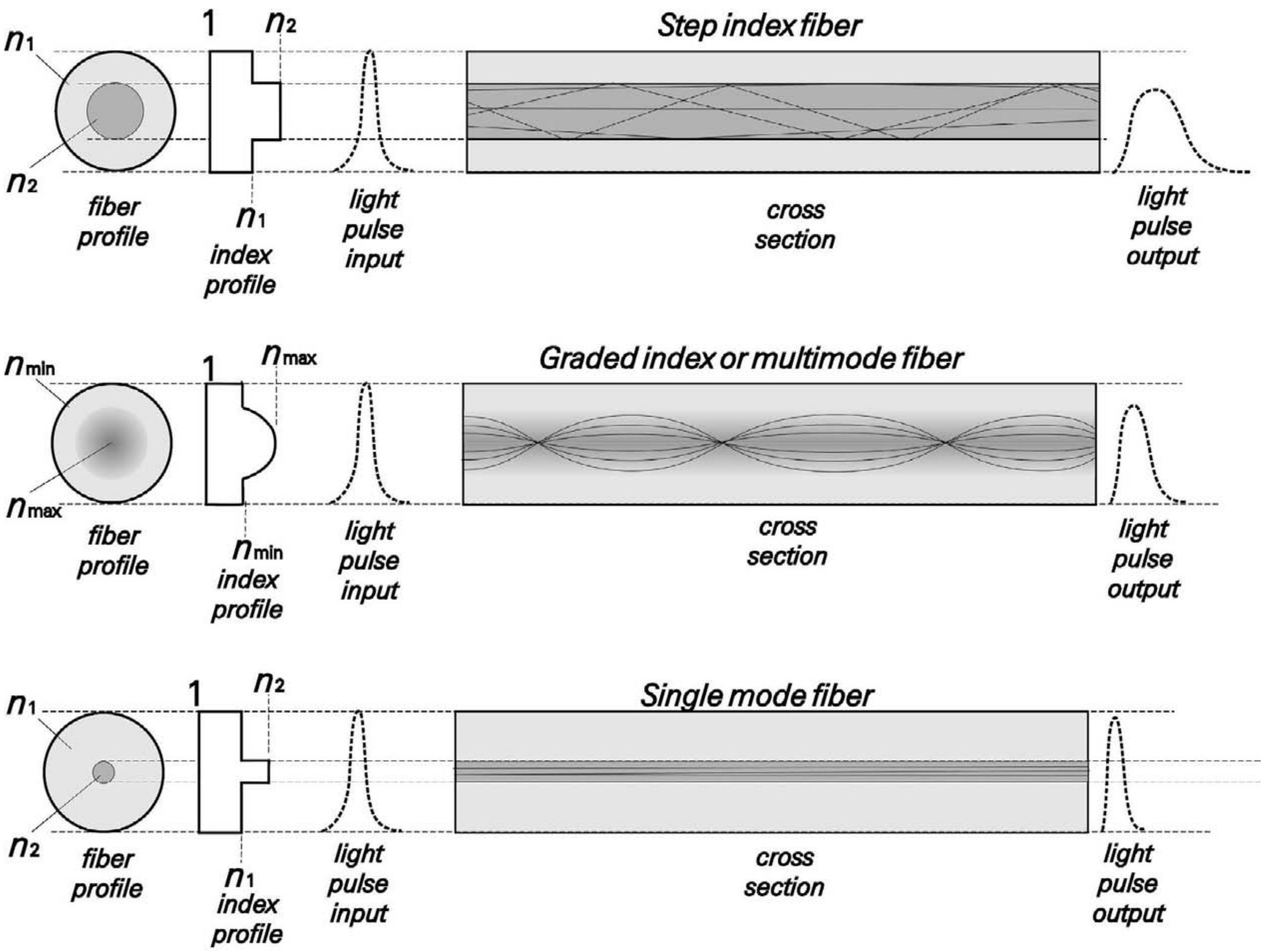
Nowadays, we are witnessing a conversion of most terrestrial hard-wired copper links to fiber.

Types of optical fibers

There are a few different types of fiber optics cables. This division is based on the path light waves take through the fiber.

As mentioned in the introduction, the basic idea is to use the total reflection effect that is a result of the different indices of refraction ($n_2 > n_1$) where n_2 is the index of the internal (***core***) fiber and n_1 is the index of the outer (***cladding***) fiber.

A typical representation of what we have just described is the ***step index*** fiber optics cable. The index



The three different types of fibers

profile is shown here, as well as how light travels through such a cable. Note the input pulse deformation caused by the various path lengths of the light rays bounced from the cylindrical surface that divides the two different index fibers. This is called a ***modal distortion***.

In order to equalize the path lengths of different rays and improve the pulse response, a ***graded index*** (or ***multi-mode***) fiber optics cable was developed. Multi-mode fiber makes the rays travel more or less at an equal speed, causing the effect of optical standing waves.

And finally, a ***single-mode*** fiber cable is available with even better pulse response and almost eliminated modal distortion.

This latter one is the most expensive of all and offers the longest distances achievable **using the same electronics**. For CCTV applications, the multi-mode and step index are adequate.

The index profiles of the three types are shown above.

Numerical aperture

The light that is injected into the fiber cable may come from various angles.

Because of the different indices of the air and the fiber, we can apply the theory of refraction where Snell's Law gives us:

$$\sin\phi_0 \, n_0 = \sin\phi_1 \, n_1 \qquad (52)$$

Understandably, n_1 is the index of the fiber core and n_0 is the index of air, which is nearly 1.

Furthermore, this gives us:

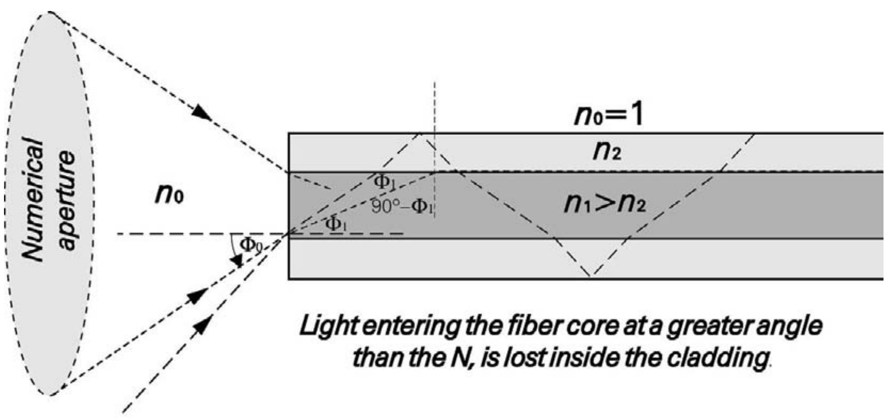
$$\sin\phi_0 = \sin\phi_1 \, n_1 \qquad (53)$$

The left-hand side of the above is accepted to be a very important fiber cable property, called ***numerical aperture*** (**NA**).

NA represents the light-gathering ability of a fiber optics cable.

In practice, NA helps us to understand how two terminated fibers can be put together and still make a signal contact.

The realistic value of a typical NA angle for a step index fiber cable is shown on the drawing.



Defining the numerical aperture

To calculate NA (basically the angle ϕ_0), it is not necessary to know the angle ϕ_1.

The following are some basic trigonometric transformations that will express NA using only the fiber indices.

Applying Snell's Law and using the drawing, we get:

$$\sin(90° - \phi_1) \, n_1 = \sin(90° - \phi_2) \, n_2 \qquad (54)$$

For a total reflection we have $\phi_2 = 0°$; therefore, the above becomes:

$$\sin(90° - \phi_1) \, n_1 = n_2 \qquad (55)$$

Since $\sin(90° - \phi_1) = \cos\phi_1$, we can write:

$$\cos\phi_1 = n_2 / n_1 \quad (56)$$

Knowing the basic rule of trigonometry,

$$\sin^2\phi + \cos^2\phi = 1 \quad (57)$$

and using equation (56), we can convert (53) into a more acceptable relation without sine and cosine:

$$\sin^2\phi_0 /n_1^2 + n_2^2/n_1^2 = 1 \quad (58)$$

$$\sin^2\phi_0 = n_1^2 - n_2^2 \quad (59)$$

$$NA = \sin\phi_0 = \text{SQRT}\ (n_1^2 - n_2^2) \quad (60)$$

Formula (60) is the well-known formula for calculating the numerical aperture of a fiber cable, based on the two known indices, the core and the cladding. SQRT stands for square root.

Obviously, **the higher this number is, the wider the angle of light acceptance will be of the cable.**

A realistic example would be with $n_1 = 1.46$ and $n_2 = 1.40$ which will give us NA = 0.41, that is, $\phi_0 = 24°$.

For a graded index fiber, this aperture is a variable, and it is dependent on the radius of the index which we are measuring, but it is lower than the step index multi-mode fiber. A single-mode 9/125 μm fiber has NA = 0.1.

Light levels in fiber optics

Light output power is measured in watts (like any other power), but since light sources used in fiber optics communications are very low, it is more appropriate to compare an output power relative to the input one, in which case we get the well-known equation for ***decibels***:

$$A_R = 10 \log (P_O/P_I) \qquad [\text{dB}] \quad (61)$$

However, if we compare a certain light power relative to an absolute value, like 1 mW, then we are talking about dBm-s, that is:

$$A_A = 10 \log (P/1\ \text{mW}) \qquad [\text{dBm}] \quad (62)$$

Working with decibels makes calculation of transmission levels much easier.

Negative decibels, when A is calculated, mean loss and positive decibels mean gain.

In the case of A_A, a negative number of dBm represents power less than 1 mW and a positive number is more than 1 mW.

The definition of dB, when comparing power values, is as shown in equation (61), but as noted earlier, there is a slightly different definition when voltage or current is compared and expressed in decibels:

$$B_R = 20 \log (V_O/V_I) \qquad [\text{dB}] \qquad (63)$$

Without going into the theory, it should be remembered that power decibels are calculated with 10 and voltage (and current) decibels are calculated with 20 times in front of the logarithm.

Light, when transmitted through a fiber cable, can be lost due to:

- Source coupling
- Optical splices
- Attenuation of the fiber due to nonhomogeneity
- High temperature and so on

When designing a CCTV system with fiber optics cables, the total attenuation is very important to know since we work with very small signals. It is therefore better to work with worst case estimates rather than using average values, which will help design a safe and quality system.

For this purpose it should be known that in most cases an 850 nm LED light power output is between 1 dBm and 3 dBm, while a 1300 nm LED has a bit less power, usually from 0 dBm to 2 dBm (note: the power is expressed relative to 1 mW).

The biggest loss of light occurs in the coupling between the LED and the fiber.

It also depends on the NA number and on whether you use step or graded index fiber.

A realistic number for source coupling losses is around –14dB (this is relative to the source power output).

Light sources in fiber optics transmission

The two basic electronic components used in producing light for fiber optics cables are:

- LEDs
- LDs

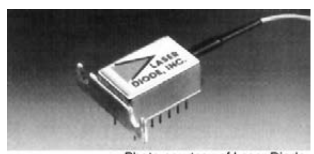


Photo courtesy of Laser Diode

Laser diode

Both of these produce frequencies in the infrared region, which is above 700 nm.

The light-generating process in both LEDs and LDs results from the recombination of electrons and holes inside a P-N junction when a forward bias current is applied. This light is actually called ***electroluminescence***.

The recombined electron/hole pairs have less energy than each constituent had separately before the recombination. **When the holes and electrons recombine, they give up this surplus energy difference, which leaves the point of recombination as photons (basic unit carriers of light).**

The wavelength associated with this photon is determined by the equation:

$$\lambda = hc/E \qquad (64)$$

where:

h is the Planck's constant, a fundamental constant in physics: 6.63×10^{-34} Joules

c is the speed of light (300×10^6 m/s)

E is the band gap energy of the P-N material

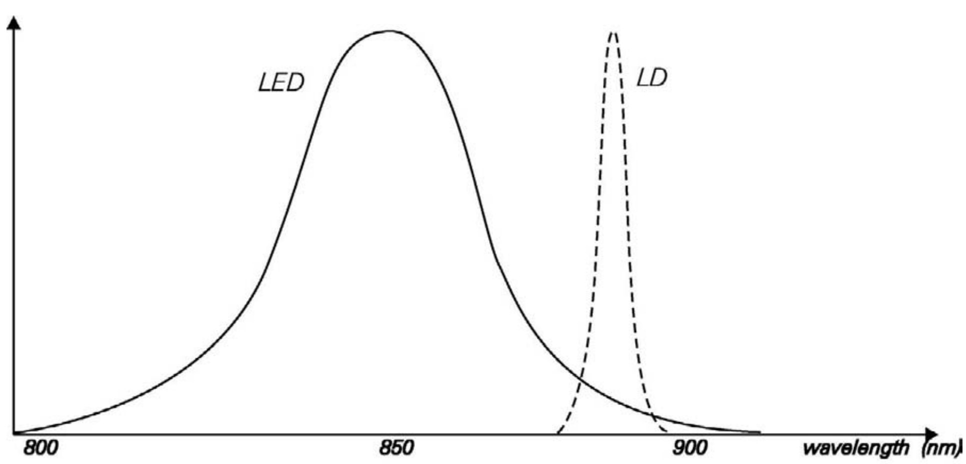
Since h and c are constant, it means that **the wavelength depends solely on the band gap energy, that is, the material in use**. This is a very important conclusion.

For pure gallium arsenide (GaAs) λ is 900 nm. For example, by adding some small amounts of aluminium, the wavelength can be lowered to 780 nm. For even lower wavelengths, other material, such as gallium arsenide phosphate (GaAsP) or gallium phosphate (GaP), is used.

The basic differences between an LED and an LD are in the generated wavelength spectrum and the angle of dispersion of that light.

An LED generates a fair bit of wavelength around the central wavelength as shown below. An LD has a very narrow bandwidth, almost a single wavelength.

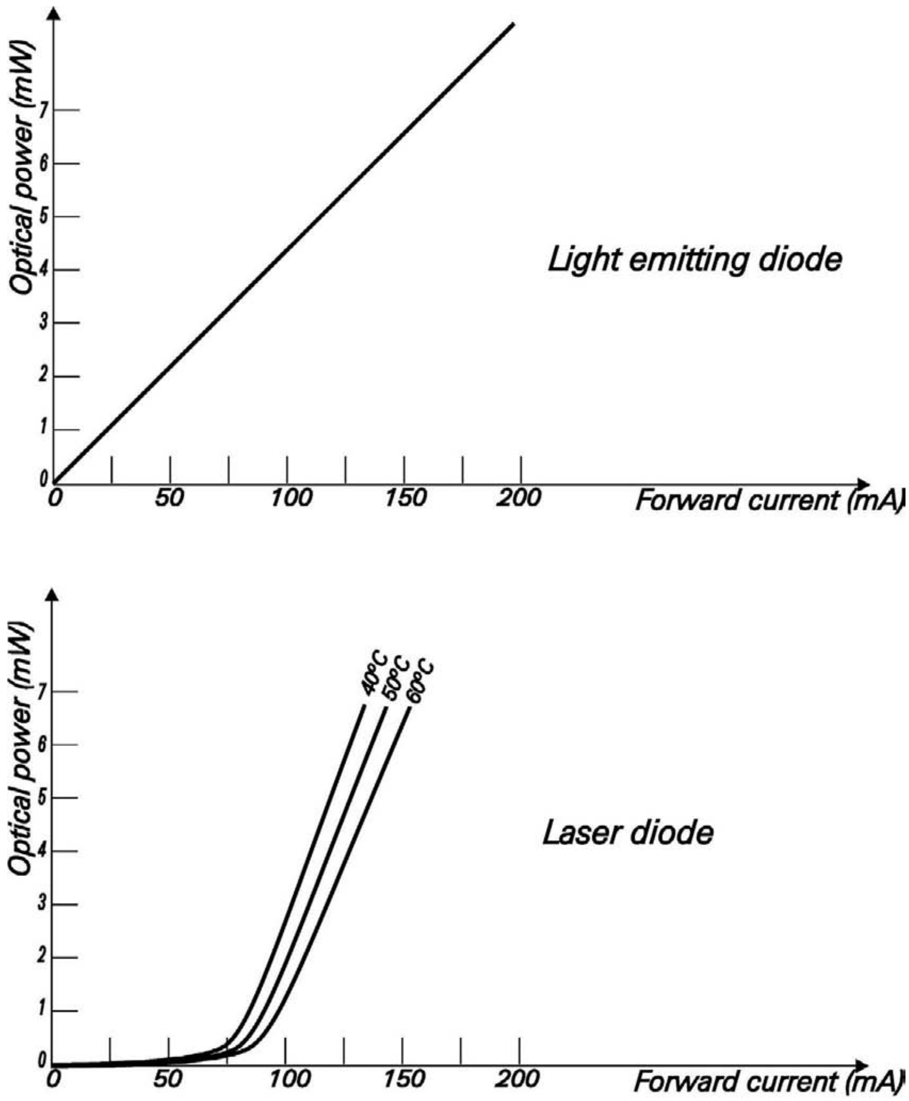
An LED P-N junction not only emits light with more frequencies than an LD, but it does so in all directions, that is, with no preferred direction of dispersion. This dispersion will greatly depend on the mechanical construction of the diode, its light absorption and reflection of the area. The radiation, however, is omnidirectional, and in order to narrow it down, LED manufacturers put a kind of focusing



LED and LD radiation spectrum

lens on top. This is still far too wide an angle to be used with a single-mode fiber cable. So this is the main reason LEDs are not used as transmitting devices with single-mode fiber cables.

An LD is built of a similar material as an LED and the light-generating process is similar, but the junction area is much smaller and the concentration of the holes and electrons is much greater. The generated light can only exit from a very small area. At certain current levels, the photon generation process gets into a **resonance** and the number of generated photons increases dramatically, producing more photons with the same wavelength and in phase. Thus, **the optical gain is achieved in an organized way and the generated light is a coherent (in phase), stimulated emission of light**. In fact, the word "laser" is an abbreviation for ***light amplification by stimulated emission of radiation***.



Light output dependence on current for LED and LD

In order to start this stimulated emission of light, an LD requires a minimum current of 5 to 100 mA, which is called a ***threshold current***. This is much higher than the threshold with normal LEDs. Once the emission starts, however, LDs produce a high optical power output with a very narrow dispersion angle.

For transmitting high frequencies and analog signals, it is important to have a light output linear with the applied drive current, as well as a wide bandwidth.

LEDs are good in respect to linearity but not so good in high-frequency reproduction compared to the LDs, although, they do exceed 100 MHz, which, for us in CCTV, is more than sufficient.

Laser diodes can easily achieve frequencies in excess of 1 GHz.

The above can be illustrated with the same analogy as when discussing magnetic recording: Imagine the light output spectrum of an LED and LD to be tips of pencils. The LED spectrum will represent the thicker and the LD the thinner pencil tip. With the thinner pencil you can write smaller letters and more text in the same space; the signal modulated with an LD will contain higher frequencies.

LEDs, however, are cheaper and linear and require no special driving electronics. An LED of 850 nm costs around $10, whereas 1300 nm is around $100. Their MTBF is extremely high (10^6 – 10^8 hrs).

LDs are more expensive, between $100 and $15,000. They are very linear once the threshold is exceeded. They often have a temperature control circuit because the operating temperature is very important, so feedback stabilization for the output power is necessary. Despite all of that, they have a higher modulation bandwidth, and a narrower carrier spectral width, and they launch more power into small fibers. Their MTBF is lower than the LEDs', although still quite high (10^5 – 10^7 hrs).

Recently, a new LED called a ***super luminescent diode*** (SLD) has been attracting a great deal of attention. The technical characteristics of the SLDs are in between those of the LEDs and LDs.

For CCTV applications, LEDs are sufficient light sources. LDs are more commonly used in multichannel wide bandwidth multiplexers or very long run single-mode fibers.

Light detectors in fiber optics

Devices used for detecting the optical signals on the other side of the fiber cable are known as ***photo diodes***. This is because the majority of them are actually one type of a diode or another.

The basic division of photo diodes used in fiber technology is into:

- P-N photo diodes (PNPD)
- PIN photo diodes (PINPD)
- Avalanche photo diodes (APD)

The PNPD is like a normal P-N junction silicon diode that is sensitive to infrared light. Its main characteristics are low respondence and high rise time.

The PINPD is a modified P-N diode where an intrinsic layer is inserted in between the P and N types of silicon. It possesses high response and low rise times.

The APD is similar to the PINPD, but it has an advantage that almost each incident photon produces more than one electron/hole pair, as a result of an internal chain reaction (avalanche effect). Consequently, the APD is more sensitive than the PIN diode, but it also generates more noise.

All these basic devices are combined with amplification and "transimpedance" stages that amplify the signal to the required current/voltage levels.

Frequencies in fiber optics transmission

The attenuation of the optical fibers can be grouped in attenuation due to material and external influences.

Material influences include:

• Rayleigh scattering. This is due to the inhomogeneities in the fiber glass, the size of which is small compared to the wavelength. At 850 nm, this attenuation may add up to 1.5 dB/km, reducing to 0.3 dB/km for a wavelength of 1300 nm and 0.15 dB/km for 1550 nm.

• Material absorption. This occurs if hydroxyl ions and/or metal ions are present in the fiber. Material absorption is much smaller than the Rayleigh scattering and usually adds up to 0.2 dB/km to the signal attenuation.

The external effects that influence the attenuation are:

• Micro-bending. This is mainly due to an inadequate cable design – inconsistency of the fiber cable precision along its length. It can amount up to several dB/km.

• Fiber geometry. This is similar to the above, but is basically due to the poor control over its drawn diameter.

The accompanying diagram on the next page shows a very important fact: that not all the wavelengths (frequencies) have the same attenuation when sent through a fiber cable.

The wavelengths around the areas indicated with the vertical dotted lines are often called ***fiber optics windows***. There are three windows:

• First window at 850 nm

• Second window at 1300 nm

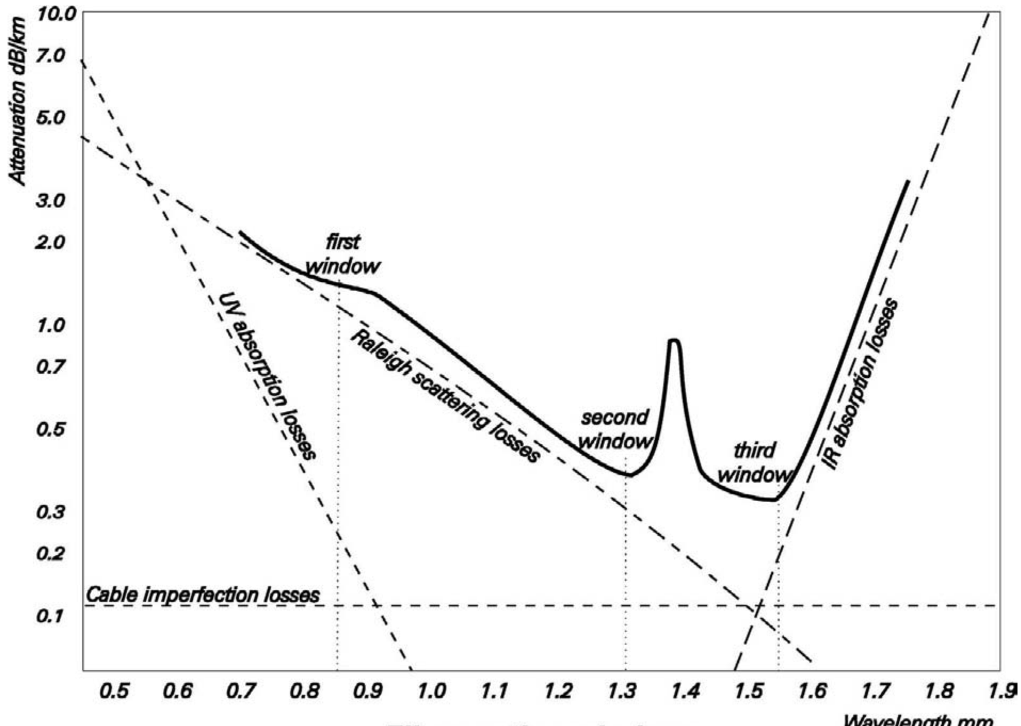
• Third window at 1550 nm

The first window is not really with minimum attenuation compared to the higher frequencies, but this frequency was first used in fiber transmission. The LEDs produced for this use were reasonably efficient and easy to make.

For short-distance applications, such as CCTV, this is still the cheapest and preferred wavelength.

The 1300 nm wavelength is becoming more commonly used in CCTV. This is the preferred wavelength for professional telecommunications as well as CCTV systems with longer cable runs, where higher light source cost is not a major factor. The losses at this frequency are much lower, as can be seen from the diagram. The difference between 850 nm and 1300 nm in attenuation is approximately 2 to 3 dB/km.

The 1550 nm wavelength has even lower losses; therefore, more future systems will be oriented toward



Fiber optics windows

this window.

For illustration purposes, a typical attenuation figure of a multi-mode 62.5/125 µm fiber cable, for an 850 nm light source, is less than 3.3 dB per kilometer. If a 1300 nm source is used with the same fiber, attenuation of less than 1 dB can be achieved. Therefore, **longer distances can be achieved with the same fiber cable, by just changing the light source**. This is especially useful with analog signals, such as the video.

When an 850 nm light source is used with 62.5/125 µm cable, we can easily have a run of at least a couple of kilometers, which in most CCTV cases is more than sufficient. However, longer distances can be achieved by using graded multi-mode fiber and even longer when a 1300 nm light source is used instead of 850 nm.

The longest run can be achieved with a single-mode fiber cable and light sources of 1300 nm and 1550 nm.

A typical attenuation figure for a 1300 nm light source is less than 0.5 dB/km, and for 1550 nm it is less than 0.4 dB/km.

Passive components

Apart from the previously mentioned photo diodes and detectors, which can also be considered as ***active devices***, there are some ***passive components*** used in fiber optics systems.

These are:

- Splices: permanent or semipermanent junctions between fibers.
- Connectors: junctions that allow an optical fiber to be repeatedly connected to and/or disconnected from another fiber or to a device such as a source or detector.
- Couplers: devices that distribute optical power among two or more fibers or combine optical power from two or more fibers into a single fiber.
- Switches: devices that can reroute optical signals under either manual or electronic control.

Fusion splicing

Two fibers are welded together, often under a microscope. The result is usually very good, but the equipment might be expensive.

The procedure of fusion splicing usually consists of cleaning the fiber, cleaving, and then positioning the two fibers in some kind of mounting blocks.

The precision of this positioning is improved by using a microscope, which is quite often part of the machine. When the alignment is achieved, an electric arc is produced to weld the two fibers. Such a process can be monitored and repeated if an unsatisfactory joint is produced.

Losses in fusion splicing are very low, usually around 0.1 dB.

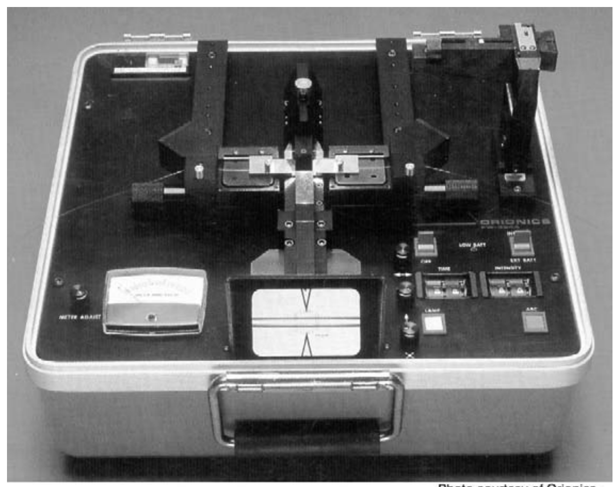


Photo courtesy of Orionics

A fusion splicing machine



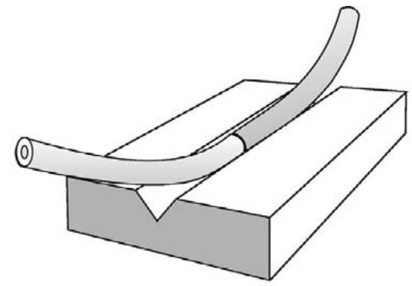
An ST connector and mechanical splicing joint

Mechanical splicing

This is probably the most common way of splicing, owing to the inexpensive tools used with relatively good results.

Fibers are mechanically aligned, in reference to

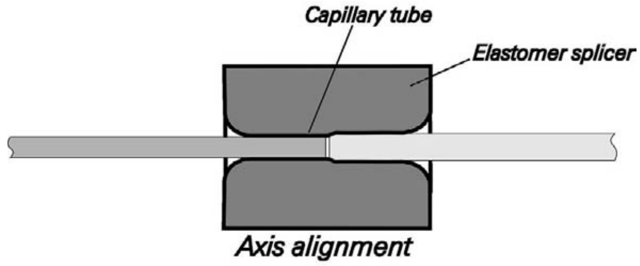
their surfaces and (usually) epoxied together. The performance cannot be as good as fusion splicing, but it may come very close to it. More importantly, the equipment used to perform the mechanical splicing is far less expensive.



Losses in a good mechanical splicing range between 0.1 and 0.4 dB.

The mechanical splicing is based on two principles:

- V groove
- Axis alignment



Mechanical splicing

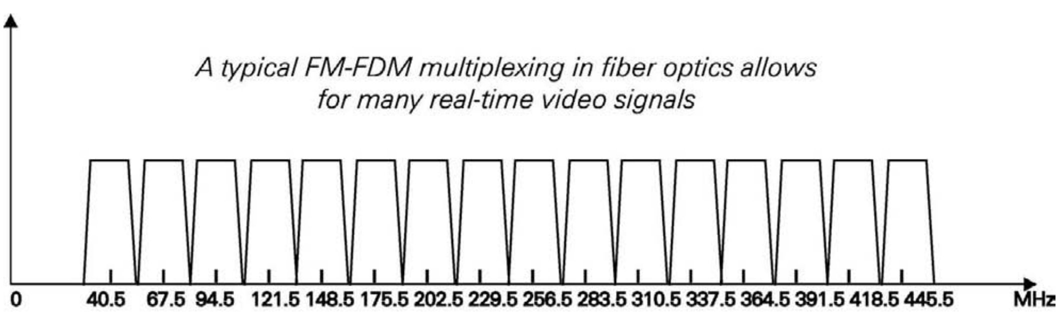
Both of these are shown in the diagrams at right.

For a good connection, the fiber optics cable needs a good termination, which is still the hardest part of a fiber optics installation. It needs high precision and patience and a little bit of practice. Anyone can learn to terminate a fiber cable and in cases where they have no such skills, installers can hire specialized people who supply the terminals, terminate the cable, and test it. The latter is the most preferred arrangement in the majority of CCTV fiber optics installations.

Fiber optics multiplexers

These multiplexers are different from the VCR multiplexers described earlier. **Fiber optics multiplexers combine more signals into one, in order to use only a single fiber cable to simultaneously transmit several live signals**. They are especially practical in systems with an insufficient number of cables (relative to the number of cameras).

There are a few different types of fiber multiplexers. The simplest and most affordable multiplexing for fiber optics transmission is by use of ***wavelength division multiplexing*** (WDM) couplers. These are couplers that transmit optical signals from two or more sources, operating at different wavelengths,



An example FM-FDM multiplexing in fiber optics

over the same fiber. This is possible because **light rays of different wavelengths do not interfere with each other**. Thus, the capacity of the fiber cable can be increased, and if necessary, bidirectional operation over a single fiber can be achieved.

Frequency-modulated frequency division multiplexing (FM-FDM) is a reasonably economical design with acceptable immunity to noise and distortions, good linearity, and moderately complex circuitry. A few brands on the market produce FM-FDM multiplexers for CCTV applications. They are made with 4, 8, or 16 channels.

Amplitude vestigial sideband modulation, frequency division multiplexing (AVSB-FDM) is another design, perhaps too expensive for CCTV, but very attractive for CATV, where with high-quality optoelectronics up to 80 channels per fiber are possible.

Fully digital **pulse code modulation, time division multiplexing** (PCM-TDM) is another expensive multiplexing, but of digitized signals, which may become attractive as digital video gains greater acceptance in CCTV.

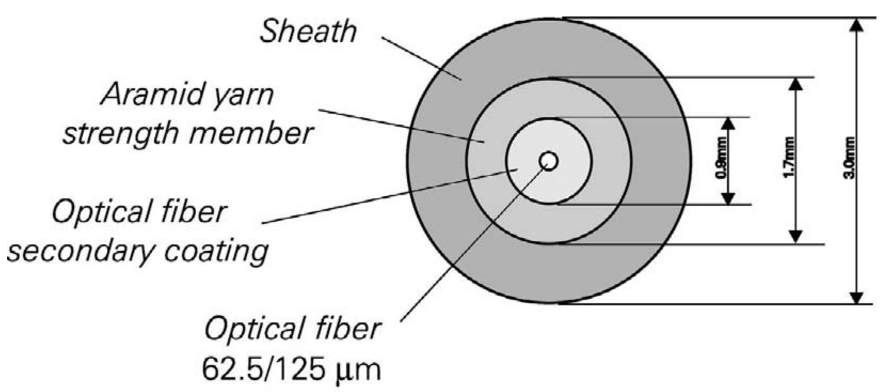
Combinations of these methods are also possible.

In CCTV we would most often use the FM-FDM for more signals over a single fiber. The WDM type of multiplexing is particularly useful for PTZ, or keyboard control with matrix switchers. Video signals are sent via separate fibers (one fiber per camera), but only one fiber uses WDM to send control data in the opposite direction.

Even though the fiber optics multiplexing is becoming more affordable it should be noted that in the planning stage of fiber installation it is still recommended that at least one spare fiber is run in addition to the one intended for use.

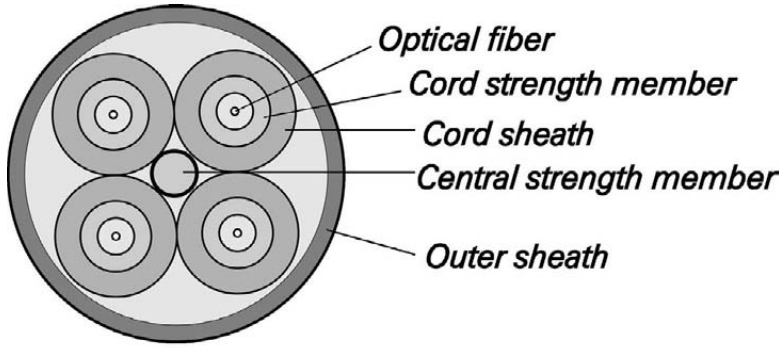
Fiber optics cables

The fiber optics itself is very small in size. The external diameter, as used in CCTV and security in general, is only 125 µm (1 µm = 10^{-6} m). Fiberglass, as a material, is relatively strong but can easily be broken when bent to below a certain minimum radius. Therefore, the aim of the cabling is to provide adequate mechanical protection and impact and crush resistance to preserve minimum bending radius as well as to provide easy handling for installation and service and to ensure that the transmission properties remain stable throughout the life of the system.



A single-fiber cable cross section

The overall design may vary greatly and depends on the application (underwater, underground, in the air, in conduit), the number of channels required, and similar. Invariably, it features some form of tensile strength member and a tough outer sheath to provide the necessary mechanical and environmental protection.



A four-fiber cable with a strength member

Fiber optics cables have various designs, such as a simple single fiber, loose tube (fiber inserted into a tube), slotted core (or open channel), ribbon, and tight buffer.

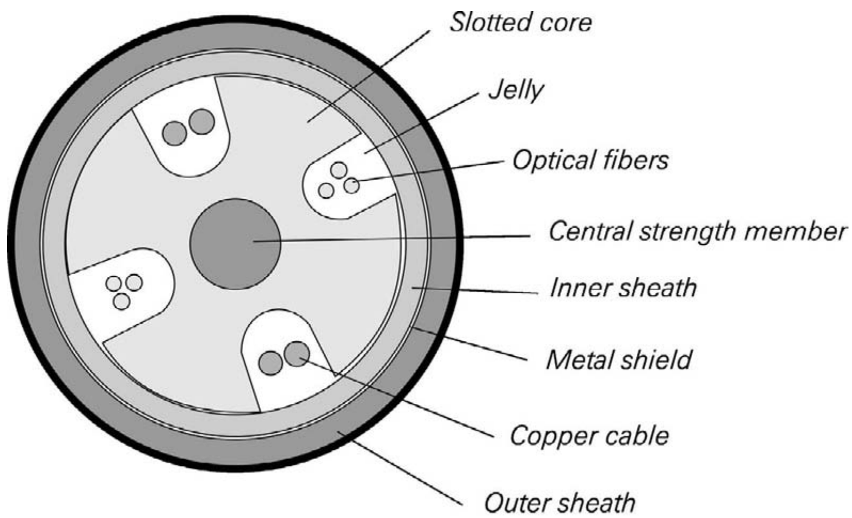
We will discuss a few of the most commonly used designs in CCTV.

Single-fiber and dual-fiber cables usually employ a fibrous strength member (aramid yarn) laid around the secondary coated fiber. This is further protected by a plastic outer sheath.

Multi-fiber cables are made in a variety of configurations.

The simplest involves grouping a number of single-fiber cables with a central strength member within the outer jacket. The central strength member can be high tensile steel wire, or a fiberglass reinforced plastic rod. Cables with this design are available with 2 to 12 or more communication fibers. When the plastic rod is applied to the central strength member, it becomes a **metal-free** optical fiber cable. Constructed entirely from polymeric material and glass, these cables are intended for use in installations within buildings. They are suitable for many applications including CCTV, security, computer links, and instrumentation. These heavy-duty cables are made extremely rugged to facilitate pulling through ducts.

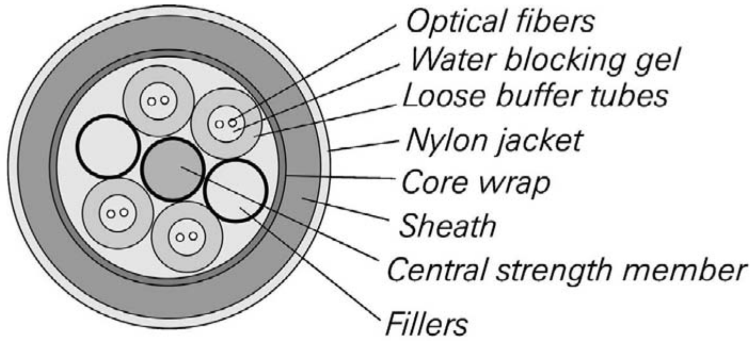
Loose tube cables are designed as a good alternative to the single core and slotted cables. The optical fibers are protected by water-blocking gel-filled polyester tubes. This type of multi-fiber cable is designed for direct burial or duct installation in long-haul applications. It can be air pressurized or gel-filled for water-blocking.



Composite optic/metallic cable

There are some other configurations manufactured with ***slotted***

polyethylene core profiles to accommodate larger numbers of fibers. This type is also designed for direct burial or duct installation in long-haul applications. It can be air pressurized or gel filled for water blocking.



A typical fiber cable with a strength member and fillers

Finally, another type of cable is the **composite optic/metallic** cable. These cables are made up of a combination of optical fibers and insulated copper wire and are designed for both indoor and outdoor use. These cables can be fully filled with a water-blocking compound to protect the fibers from moisture in underground installations, for example.

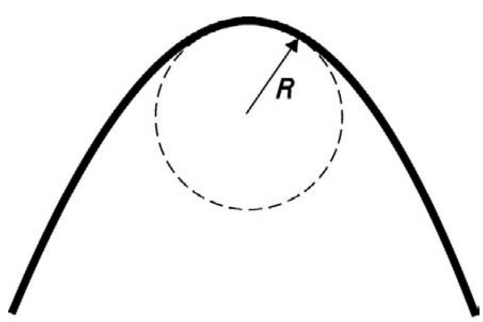
Since the fiber cable is much lighter than other cables, the installations are generally easier compared to an electrical cable of the same diameter.

The protection they have will allow fiber cables to be treated in much the same way as electrical cables. However, care should be taken to ensure that the manufacturer's ***recommended maximum tensile and crushing force*** are not exceeded.

Within a given optical cable, tension is carried by the strength members, usually fiber-reinforced plastic, steel, kevlar, or a combination, that protect the comparatively fragile glass fibers. If the cable tension exceeds the manufacturer's ratings, permanent damage to the fibers can result.

The rating to be observed, as far as installation tension is concerned, is the ***maximum installation tension***, expressed in Newtons or kilo-Newtons (N or kN). A typical cable has a tension rating of around 1000 N (1 kN). To get an idea of what a Newton feels like, consider that 9.8 N of tension is created on a cable hanging vertically and supporting a mass of 1 kg. In addition, manufacturers sometimes specify a maximum long-term tension. This is typically less than half of the maximum installation tension.

As with coaxial cables, optical fiber cables must not be bent to a tighter curve than their rated ***minimum bending radius***. In this case, however, the reason is not the electrical impedance change, but rather **preventing the fiber from breaking and preserving the total angle of reflection**. The minimum bending radius varies greatly for various cable constructions and may even be specified at different values, depending on the presence of various levels of tension in the cable. Exceeding the bending radius specification will place undue stress on the fibers and may even damage the stiff strength members.



Minimum bending radius

Whenever a cable is being handled or installed, it is most

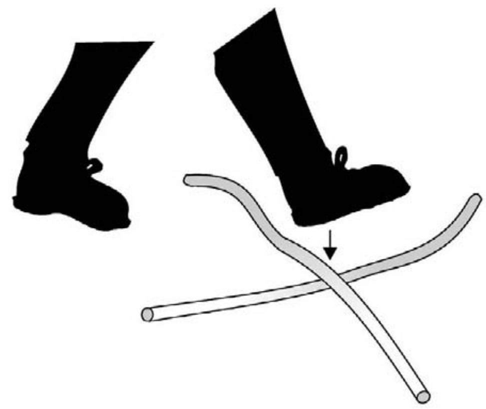
important to keep the curves as smooth as possible.

Often, during an installation, the cable is subject to crush stresses such as being walked on or, even worse, driven over.

Although great care should be taken to avoid such stresses, the cable is able to absorb such forces up to its rated **crush resistance** value. Crush resistance is expressed in N/m or kN/m of cable length. For example, a cable with a specified crush resistance of 10 kN/m can withstand a load of 1000 kg spread across a full 1 m of cable length (10 Newtons is approximately the force that results from a 1 kg mass). If we consider a size 9 boot (European 42) to be 100 mm wide, then the cable will support a construction worker who weighs 100 kg standing on one foot squarely on the cable. However, a vehicle driving over this cable may exceed the crush resistance spec and probably damage the cable.

Be careful if a cable has one loop crossing over another, then the forces on the cable due to, say, a footstep right on the crossover will be **greatly magnified because of the smaller contact area**. Likewise in a crowded duct, a cable can be crushed at localized stress points even though the weight upon it may not seem excessive.

An optical cable is usually delivered wound onto wooden drums with some form of heavy plastic protective layer or wooden cleats around the circumference of the drums. When handling a cable drum, due consideration should be given to the mass of the drum. The most vulnerable parts of a cable drum are the outer layers of the cable. This is especially the case when the cable drums are vertically interleaved with each other. Then damage due to local crushing should be of concern. To alleviate such problems, the drums should be stacked either horizontally, or, if vertically, with their rims touching. Do not allow the drums to become interlocked. Also, when lifting drums, with a forklift for example, do not apply force to the cable surface. Instead, lift at the rims or through the center axis.



Crushing force can easily be exceeded



Different types of fiber connectors

Installation techniques

Prior to installation, the cable drums should be checked for any sign of damage or mishandling. The outer layer of a cable should be carefully examined to reveal any signs of scratching or denting. Should a drum be suspected of having incurred damage, then it should be marked and put aside. For shorter lengths (i.e., < 2 km) a simple continuity check can be made of the whole fiber using a penlight as a light source. A fiber cable, even though used with infrared wavelengths, transmits normal light just as well. This is useful in finding out if there are serious breaks in the cable. Continuity of the fiber can be checked by using a penlight.

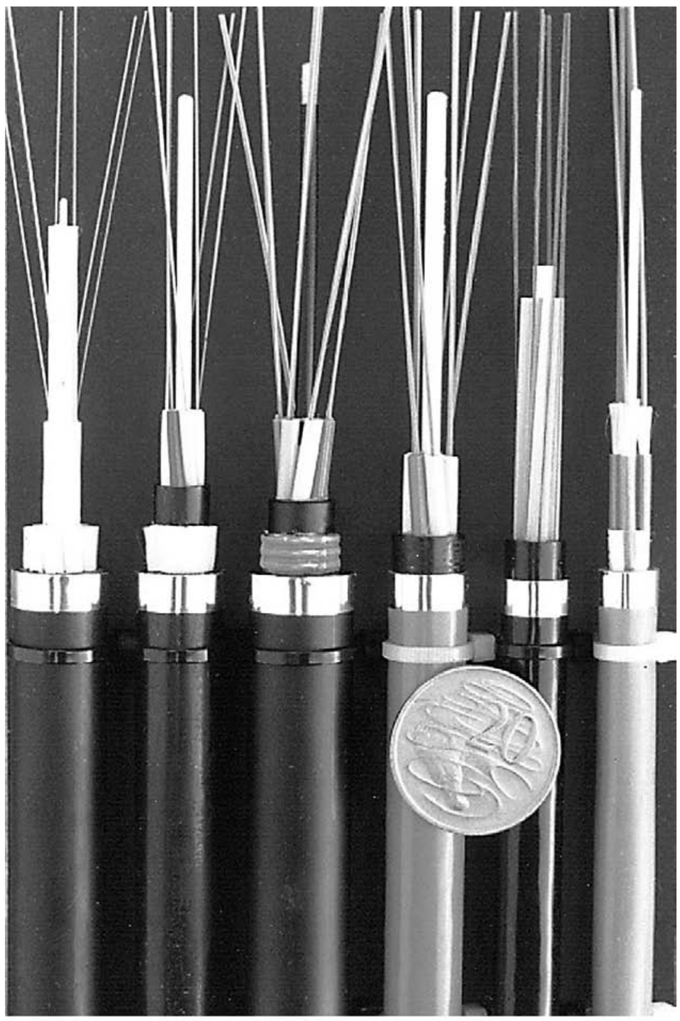
The following precautions and techniques are very similar to what was said earlier for coaxial cable installations, but since it is very important we will go through it again.

Before cable laying commences, the route should be inspected for possible problems such as feed-through, sharp corners, and clogged ducts. Once a viable route has been established, the cable lengths must be arranged so that should any splices occur, they will do so at accessible positions.

At the location of a splice it is important to leave an adequate overlap of the cables so that sufficient material is available for the splicing operation. Generally, the overlap required is about 5 m when the splice is of the in-line type. A length of about 2.5 m is required where the cable leaves the duct and is spliced.

Note that whenever a cable end is exposed it must be fitted with a watertight end cap. Any loose cable should be placed to avoid bending stress or damage from passing traffic. At either end of the cable run, special lengths are often left depending on the configuration planned.

Foremost consideration, when burying a cable, is the prevention of damage due to excessive local points loading. Such loading occurs when backfill material is poured onto or an uneven trench profile digs into the cable, thus either puncturing the outer sheath or locally crushing the cable. The damage may become immediately obvious, or it may take some time to show itself. Whichever, the cost of digging up the cable and repairing it makes the expenditure of extra effort during laying well worthwhile.



Various types of multi-fiber cables

When laying cables in trenches, a number of

precautions must be taken to avoid damage to the cable or a reduction in cable life expectancy.

The main protection against cable damage is laying the cable on a bed of sand approximately 50 to 150 mm deep and backfilling with another 50 to 150 mm of sand. Due care needs to be taken in the digging of the trench so that the bottom of the trench is fairly even and free of protrusions. Similarly, when backfilling, do not allow rock soil to fall onto the sand because it may put a rock through the cable.

Trench depth is dependent upon the type of ground being traversed as well as the load that is expected to be applied to the ground above the cable. A cable in solid rock may need a trench of only 300 mm or so, whereas a trench crossing a road in soft soil should be taken down to about 1 m. A general-purpose trench in undemanding situations should be 400 to 600 mm deep with 100 to 300 mm total sand bedding.

The most straightforward technique is to lay the cable directly from the drum into a trench or onto a cable tray. For very long cable runs, the drum is supported on a vehicle and allowed to turn freely on its axis, or it can be held and rested on a metal axis. As the vehicle (or person) advances, the cable is wound off the drum straight to its resting place. Avoid excessive speed and ensure that the cable can be temporarily tied down at regular intervals prior to its final securing.

Placing an optical cable on a cable tray is not particularly different from doing so with conventional cables of a similar diameter. The main points to observe are, again, minimum bending radius and crush resistance.

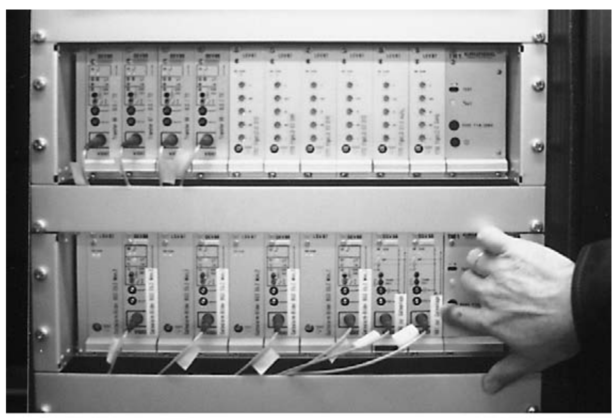
The minimum bending radius must be observed even when the cable tray does not facilitate this. The tendency to keep it neat and bend the optical cable to match other cables on the tray must be avoided.

Crush loading on cable trays can become a critical factor, where the optical cable is led across a sharp protrusion or crossed over another cable. The optical cable can then be heavily loaded by further cables being placed on top of it or personnel walking on the tray. Keep the cable as flat as possible and avoid local stress points.

The pulling of optical cables through ducts is no different from conventional cabling. At all times use only the amount of force required but stay below the manufacturer's ratings.

The types of hauling eyes and cable clamps normally used are generally satisfactory, but remember that the strength members, not the outer sheath, must take the load.

If a particular duct requires a lubricant, then it is best to obtain a recommendation from the cable manufacturer. Talcum powder and bean bag polystyrene beans can also be quite useful in reducing friction.



Fiber optics receiver modules

In some conditions, the cable may already be terminated with connectors. These must be heavily protected while drawing the cable. The connectors themselves must not be damaged or contaminated, and the cable must not experience any undue stress around the connectors or their protective sheathing.

Once the cable is installed it is often necessary to tie it down. On a cable tray, the cable can be held down simply with nylon ties. Take particular care to anchor the cable runs in areas of likely creep. On structures that are unsuited to cable ties, some form of saddle clamp is recommended. Care is required in the choice and use of such devices so that the cable crush resistance is not exceeded and so that the outer jacket is not punctured by sharp edges. Clips with molded plastic protective layers are preferred and only one clip should be used for each cable. Between the secured points of a cable it is wise to allow a little slack rather than to leave a tightly stretched length that may respond poorly to temperature variations or vibration.

If the cable is in some way damaged during installation, then leave enough extra cable length around the damaged area so that an additional splice can be inserted.

The conclusion is that **installation of fiber cables is not greatly different from conventional cables, and provided a few basic concepts are observed, the installation should be trouble free.**

Fiber optic link analysis

Now that we have learned the individual components of a fiber optics system – the sources, cables, detectors, and installation techniques – we may use this in a complete system. But before the installation, we first have to do a link analysis, which shows how much signal loss or gain occurs in each stage of the system. This type of analysis can be done with other transmission media, but it is especially important with fiber optics because the power levels we are handling are very small. They are sufficient to go over many kilometers, but can easily be lost if we do not take care of the microscopic connections and couplings.

The goal of the link analysis is to determine the signal strength at each point in the overall system and to calculate if the power at the receiver (the detector) are sufficient for acceptable performance. If it is not, each stage is examined and some are upgraded (usually to a higher cost), or guaranteed performance specifications (distance, speed, errors) are reduced.

For fiber optics systems, the link analysis should also include unavoidable variations in performance that occur with temperature as a result of component aging and from manufacturing tolerance differences between two nearly identical devices. In this respect, fiber optics systems need more careful study than all-electronic systems as there is greater device-to-device variation, together with larger performance changes due to time and temperature.

As a practical example, the diagram on the next page shows a basic point-by-point fiber optics system, which consists of an electrical data input signal, a source driver, an optical source, a 1 km optical fiber with realistic maximum attenuation of 4 dB/km, an optical detector, and the receiver electronics.

We have assumed that the system is handling digital signals, as is the case with PTZ control, but the

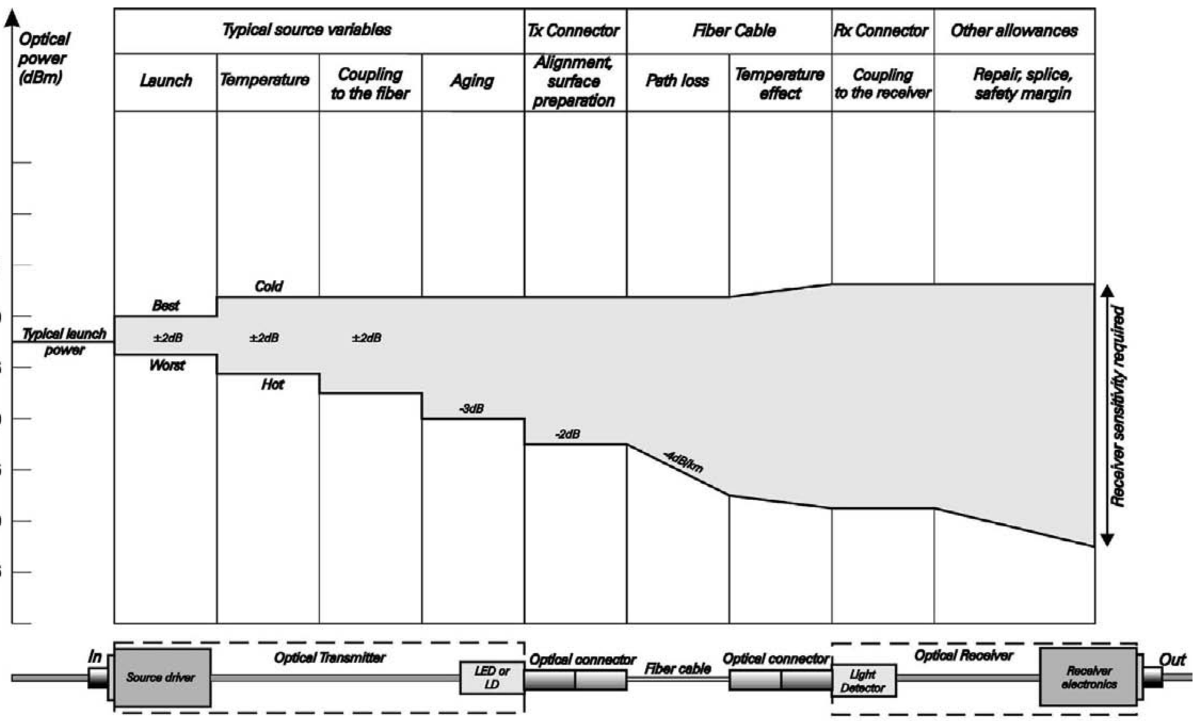
logic will be very similar when analog signal budgeting is calculated.

The calculation begins with the optical output power of the source (–12 dBm in this case) and ends with the power that is seen by the detector.

This analysis looks at each stage in the system and shows both the best and worst case power loss (or gain) for each link as a result of various factors, such as coupling losses, path losses, normal parts tolerance (best and worst for a specific model), temperature, and time.

The analysis also allows for an additional 5 dB signal loss that will occur if any repairs or splices are made over the life of the system.

The conclusion of the example is that the received optical power, for a signal to be recognized, can be anywhere between +7 dB (in the best case) and –23 dB (in the worst case) relative to the nominal source value. Technically, +7 dB would mean amplification, which is not really what we have, but rather it refers to the possible tolerance variations of the components. Therefore, the receiving detector must handle a dynamic range of optical signals from –5 dBm (–12 dBm + 7 dB = –5 dBm) to –35 dBm (–12 dBm – 23 dB = –35 dBm), representing a binary 1. Of course, when the source is dark (no light, which means binary 0), the received signal is also virtually zero (except for the system noise).



Link analysis is very important prior to installation of fiber cables.

It is understandable that a digital signal can go further in distance, using the same electronics and fiber cable, than an analog video signal, simply because of the big error margins digital signals have. Nevertheless, a similar analysis can be performed with analog signals. If however, we are not prepared or do not know how to, we can still get an answer to the basic question, Will it work? Unfortunately, the answer can only be obtained once the fiber is installed. To do so we need an instrument that measures cable continuity as well as attenuation. This is the optical time domain reflectometer.

OTDR

An ***optical time domain reflectometer*** (OTDR) is an instrument that can test a fiber cable after it has been installed, to determine the eventual breaks, attenuation, and the quality of termination.

The OTDR sends a light pulse into one end of the optical fiber and detects the returned light energy versus time, which corresponds directly to the distance of light traveled.

It requires connection to only one end of the cable and it actually shows the obvious discontinuity in the optical path, such as splices, breaks, and connectors.

It uses the physical phenomenon known as ***Rayleigh back-scattering***, which occurs within the fiber, to show the signal attenuation along the fiber's length. As a light wave travels through the fiber, a very small amount of incident light in the cable is reflected and refracted back to the source by the atomic structure and impurities within the optical fiber. This is then measured and shown visually on a screen and/or printed out on a piece of paper as evidence of the particular installation. Eventual breaks in a fiber cable are found most easily with an OTDR. Being an expensive instrument, an OTDR is usually hired for a fiber optics installation evaluation or used by the specialized people that terminate the cable.

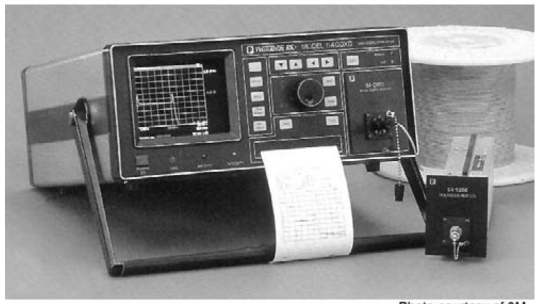
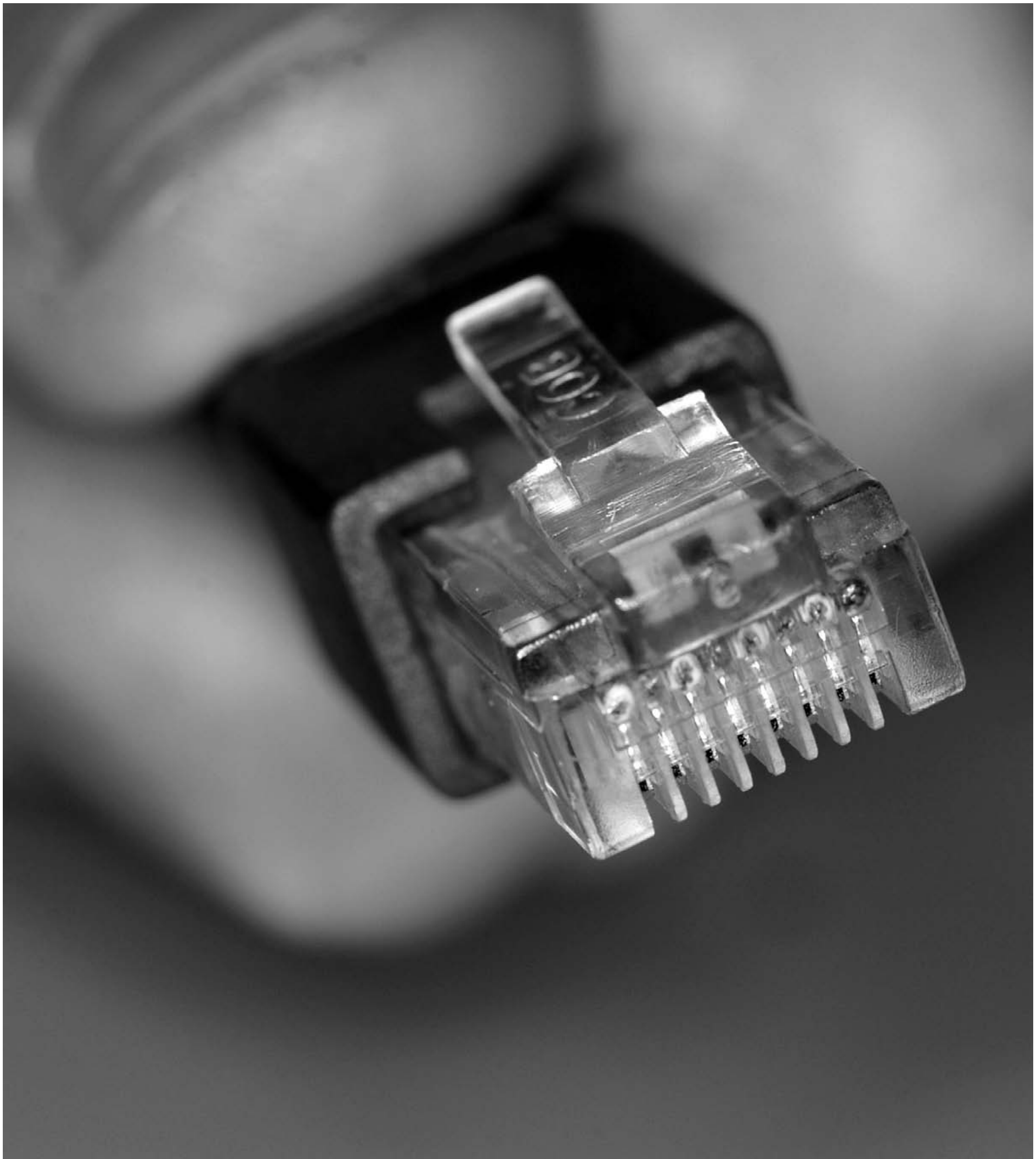


Photo courtesy of 3M

An optical time domain reflectometer



11. Networking in CCTV

The Information Technology era

Today's world is, without any doubt, the world of ***Information Technology***, or, as many would refer to it, the **IT world**.

In CCTV, we are usually looking for visual information about an event, an intruder, or a procedure, such as who entered the building before it caught fire, or what is the procedure during the heart surgery, or what is the license plate of a car involved in a collision.

So, how is information defined, and why is it so important?

Information is any communication or representation of knowledge such as facts, data, or opinions, in any medium or form, including textual, numerical, graphic, cartographic, narrative, or audiovisual forms.

Human knowledge grows exponentially, and what has been achieved only in the last few decades, for example, far exceeds the knowledge accumulated through thousands of years before that. The amount of information in each and particular human activity is so large that without proper understanding and management of such information we would lose track of what we know and where we are heading. Because the information grows exponentially people have seen a need for a complete new subject – IT – that deals with such a large amount of information.

IT is part of the larger scope of things that are especially interesting for us in the CCTV industry, and it is concerned with the hardware and software that processes information, regardless of the technology involved, whether this is digital video recorders, computers, wireless telecommunications, or others.

Because of the large amount of information recorded in our daily lives, **reliable, fast, and efficient access** to such information is of paramount importance.

Filing cabinets and mountains of papers have given way to computers that store and manage information electronically. Colleagues and friends thousands of kilometers apart can share information instantaneously, just as hundreds of workers in a single location can simultaneously review research data maintained on-line. Students, doctors, and scientists can study, research, and exchange information even if they are continents apart. **Computer networks are the glue that binds these elements together.**

The large number of such networks forms the global network called the ***World Wide Web***, or as we all know it, ***the Internet***. This only started in the 1980s, not much more than 20 years before the writing of this book, and yet most of the research and study I had to do for this book was done using the Internet.

The Internet is probably one of the most important human achievements ever.

The Internet is truly a global network, a community of knowledge and information where everybody can join in without a passport, regardless of their skin color, age, agenda, or religion.

In order to understand the use of IT, networks, and digital technology in today's CCTV, we have to dedicate some pages to the networking fundamentals.

Computers and networks

Before defining a network, we have to define the basic intelligent device that is a main part of any network. This is the computer.

Computers are so much in our daily lives that not only can we not live without them, but they are in all avenues of our daily lives so it is difficult to define them accurately. One of the many definitions of a computer is as **an electronic device designed to accept digital information (data input), perform prescribed mathematical and logical operations at high speed (processing), and supply the results of these operations (output)**. Now, this could easily refer to a digital calculator, and it would probably be correct, but in CCTV we will use the term ***computer*** to define **an electronic device that is composed of hardware (main processor – CPU, memory, and a display output) and software (Operating System and applications) and which executes a set of instructions as defined by the software.**

In the early years of the computer, numbers and high-speed calculations were the primary area of computer usage. As the processing speed and computer power grew, the processing of images, video, and audio became more frequent and this is the area of our interest.

Initially, in CCTV, computers were used most often in video matrix switchers to intelligently switch cameras onto monitors based on logical processing of external alarm inputs as well as manual selection. Computers are also used in monitoring stations where thousands and thousands of alarms are processed and logged.



Courtesy of Fast Video Security AG

A typical computer of a digital video recorder (DVR)

These days computers are used in many new CCTV products where digital video capturing, processing, compression, and archiving are done. The vast majority of these devices are digital video recorders – DVRs – but IP cameras, even though small, have

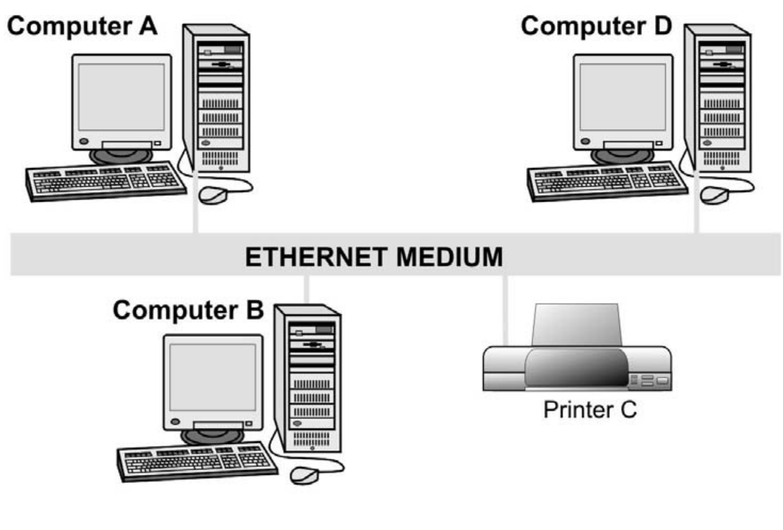
hardware and software with equivalent functionality of a computer.

All such computers can work on their own, but their real power comes to effect when they are put in a network environment.

A network is simply a group of two or more computers linked together.

Networking allows one computer to send information to and receive information from another. We may not always be aware of the numerous times we access information on computer networks. The Internet is the most conspicuous example of computer networking, linking millions of computers around the world, but smaller networks play a role in information access on a daily basis. Many libraries and book shops have replaced their card catalogues with computer terminals that allow patrons to search for books far more quickly and easily. Many companies exchange all their internal information using their own LANs; product leaflets and CCTV system designs are quoted electronically using networks. Facsimile machines are getting less use. Many Internet search engines help millions of people find the information they need. In each of these cases, networking allows many different computers in multiple locations to access a shared database.

Computers in CCTV are becoming more dominant, regardless of whether they run on a full-blown operating system (OS), such as Windows or Linux, or on an embedded OS residing on a chip. One of the main and indispensable features of computers is their ability to connect to other computers and share information via networks. And the fact is – networks are already in place in many businesses, organizations and even homes. Fitting a CCTV system to such networks is just a matter of connecting the LAN cable to a digital video recorder, to a network-ready camera, or perhaps to a computer fitted with a special video capturing card. With some minor network settings the CCTV system can be up and running in a very short period of time.



An example of a small computer network

This ease of network retrofitting and installation is one of the major attractions (though not the only one) of networks for CCTV.

This is not to say that the modern network CCTV systems have to be installed on existing networks. Many designers would actually create a complete new and separate, parallel network, simply because then the system becomes even more secure, dedicated, and most importantly does not affect the data traffic of the normal, everyday business usage network.

Once we get to this stage of having networked CCTV, there are many new

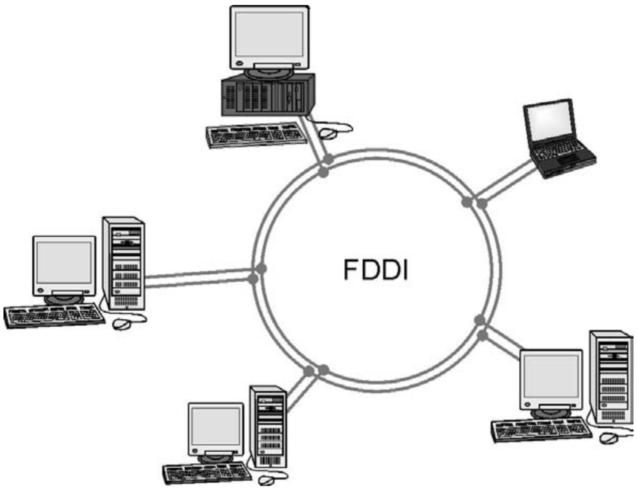
issues and limitations we face and need to understand in order to further improve or modify our system design.

Later in the book we are going to get deeper into each of these issues, but first, let us start with the basics of the networking and then clarify some of the key concepts and terminology used.

LAN and WAN

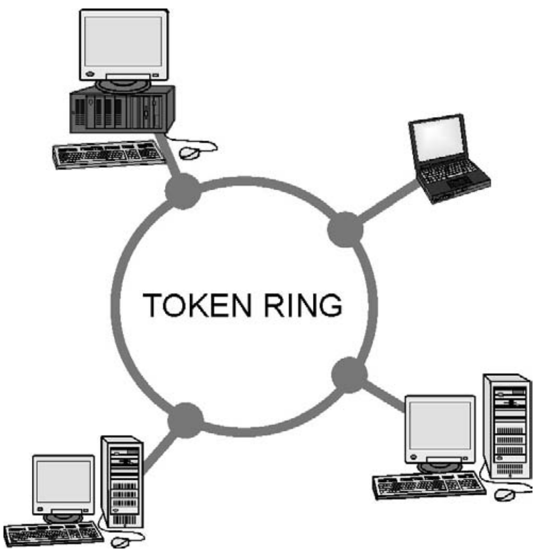
There are a few types of network transmission configurations and methods (protocols). These are the ***Fiber Distributed Data Interface*** (FDDI), the ***Token Ring*** (as specified by the IEEE 802.5 recommendation), and the ***Ethernet*** (specified by IEEE 802.3 recommendation).

Of the three, **the most popular**, and the one we will devote most of the space in this book to, **is the Ethernet.**



Ethernet is used in over 85% of the world's LANs, primarily because it is a simple concept, easy to understand, implement, and maintain; it allows low-cost network implementations; it provides extensive topological flexibility; and it guarantees interconnection and operation of various products that comply with the Ethernet standards, regardless of the manufacturer and operating system used on the computer.

Depending upon the scale of such network configurations, we have two major groups: ***Local Area Networks*** (LANs) and ***Wide Area Networks*** (WANs).

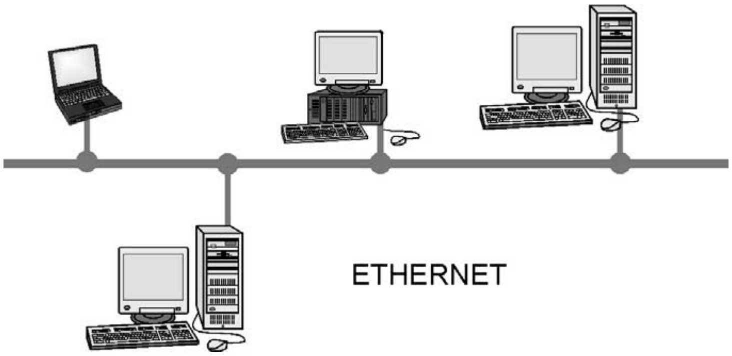


The Local Area Network (LAN) connects many devices that are relatively close to each other, usually in the same building. A typical example is a business or a company with at least a couple of computers. Sometimes this configuration is called the Intranet.

In a classic LAN configuration, one computer is nominated as the server. It stores all of the software that controls the network, including the software that can be shared by the computers attached to the network. Computers connected to the server are referred to as clients (or workstations). On most LANs, cables are used to connect the network interface cards (NIC) in each computer.

The Wide Area Network (WAN) connects a number of

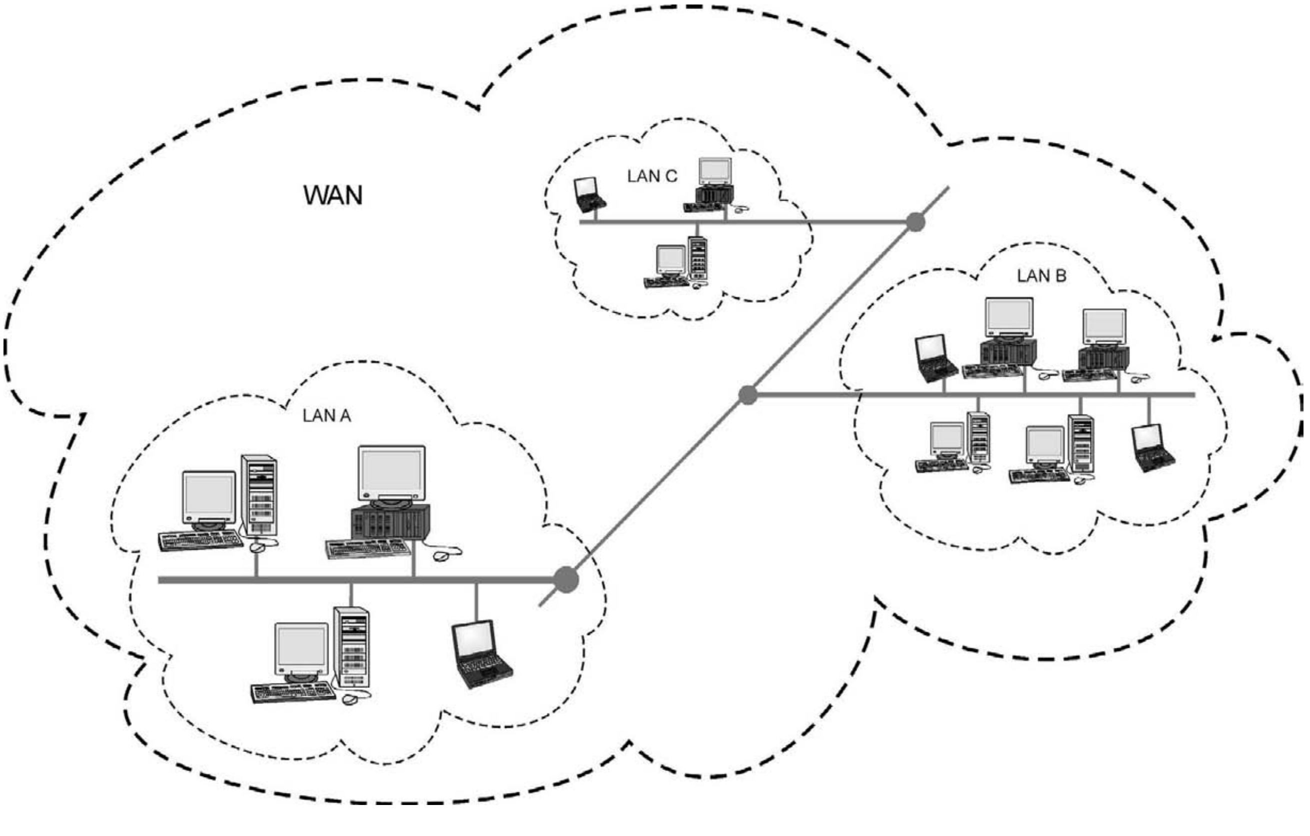
devices that can be many kilometers apart. For example, if a company has offices in two major cities, hundreds of kilometers apart, each of their LANs would most likely be configured in WAN formation, using dedicated lines leased from the local telephone company, or any available ISDN, ADSL, or other network connections.



WANs connect larger geographic areas, such as interstate, or country to country. Satellite uplinks or dedicated transoceanic cabling can be used to connect this particular type of network. WANs can be highly complex systems, as they may be connecting local and metropolitan networks to global communications networks like the Internet. To the user, however, a WAN will appear no more complex than a LAN.

In comparison to WANs, LANs are faster and more reliable, but improvements in technology continue to blur the line of demarcation and have allowed LAN technologies to connect devices tens of kilometers apart, while at the same time greatly improving the speed and reliability of WANs. This in turn blurs the line between the WANs and the Internet.

The Internet can be considered as the largest global WAN.



LAN and WAN example

Networking enables the user to access data from any location. This means an employee of a company in City A can send (upload) or receive (download) a file to a colleague in City B in a few seconds. The file can be a quotation document, a product leaflet, a program, or a digital photo.

In CCTV, we are interested mostly in video images (still images or a motion sequence), but other details such as audio, alarms, and various data logged during the system operation, can also be accessed. The principles in a network are the same. With the appropriate security level and a correct password, all such CCTV information can be accessed, copied, and displayed from anywhere on the network.

Understandably, if typical analog cameras are used in a CCTV system, they have to be first converted to digital (unless the cameras are already producing digital output) in order to be recognized and processed by the network computers. We will talk more about the digitization and compression of the video later in the book, but it is important to note that once the information is converted to digital, it is easily shared, copied, printed, transferred, stored, and used, providing one has the correct authorization levels.

This is a very important advantage in security applications since remote sites can be monitored and systems can be controlled from anywhere at any time. Most digital video recorders, or network cameras, are designed to allow you to view information from a remote location as if you were physically there.



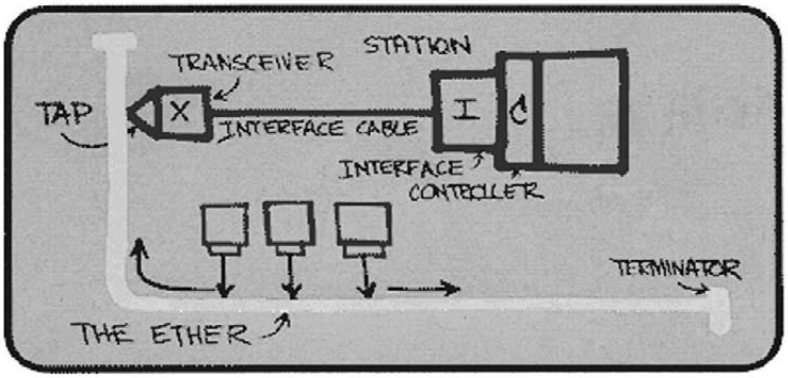
A typical network camera

Ethernet

First, let us present a little bit of history.

In 1973, at Xerox Corporation's Palo Alto Research Center (more commonly known as PARC), researcher ***Bob Metcalfe*** designed and tested the first Ethernet network. While working on a way to link Xerox's "Alto" computer to a printer, Metcalfe developed the physical method of cabling that connected devices on the Ethernet as well as the standards that governed communication on the cable. The data rate of such connection was around 3 megabits per second (3 Mb/s).

Metcalfe's original paper described Ethernet as *"a branching broadcast communication system for carrying digital data packets among locally distributed computing stations. The packet transport mechanism provided by Ethernet has been used to build systems which can be viewed as either local computer networks or loosely coupled multiprocessors. An Ethernet's shared communication facility, its Ether, is a passive broadcast medium with no central control. Coordination of access to the Ether for packet broadcasts is distributed among the contending transmitting stations using controlled statistical arbitration. Switching of packets to their destinations on the Ether is distributed among the receiving stations using packet address recognition."*



The original Metcalfe Ethernet concept drawing

After this event, a consortium of three companies – Digital Equipment Corporation (DEC), Intel, and Xerox – produced a joint development around 1980, which defined the 10 Mb/s Ethernet version 1.0 specification. In 1983, the ***Institute of Electrical and Electronic Engineers*** (IEEE) produced the IEEE 802.3 standard, which was based on, and was very similar to, the Ethernet version 1.0.

In 1985 the official standard **IEEE 802.3** was published, which **marks the beginning of the new era**, leading the way to the birth of the Internet a few years later.

Ethernet has since become the most popular and most widely deployed network technology in the world. Many of the issues involved with Ethernet are common to many network technologies, and understanding how Ethernet addressed these issues can provide a foundation that will improve your understanding of networking in general.

The main Ethernet categories

10 Mb/s Ethernet (IEEE 802.3)

This Ethernet category refers to the original shared media Local Area Network (LAN) technology running at 10 Mb/s. Ethernet can run over various media such as twisted pair and coaxial. ***10 Mb/s Ethernet*** is distinct from other higher speed Ethernet technologies such as FastEthernet, Gigabit Ethernet, and 10 Gigabit Ethernet.

Depending on the media, 10 Mb/s Ethernet can also be referred to as:

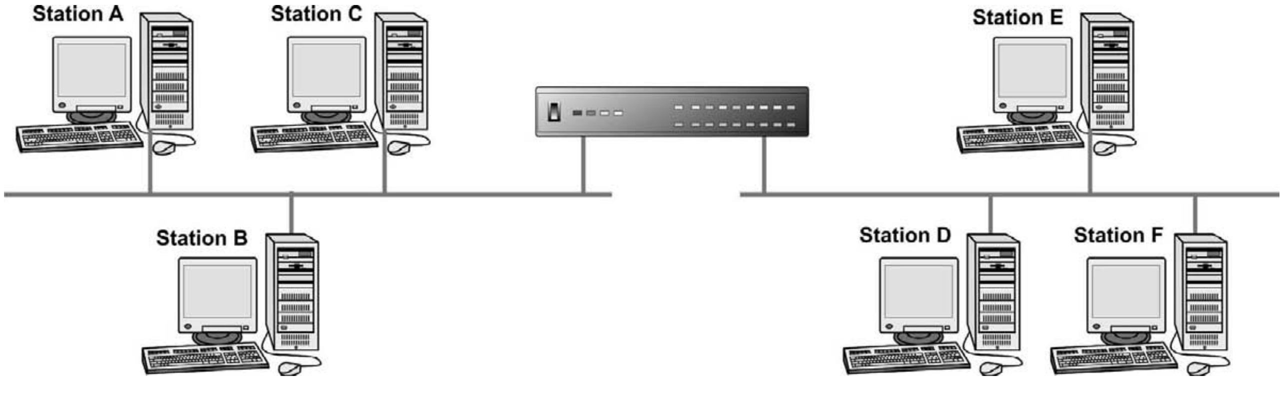
- 10BaseT – Ethernet over Twisted Pair Media
- 10BaseF – Ethernet over Fiber Media
- 10Base2 – Ethernet over Thin Coaxial Media
- 10Base5 – Ethernet over Thick Coaxial Media

Fast Ethernet (IEEE 802.3U)

Fast Ethernet covers a number of 100 Mb/s Ethernet specifications. It offers a speed increase 10 times that of the 10BaseT Ethernet specification, while preserving such qualities as frame format, MAC mechanisms, and MTU. Such similarities allow the use of existing 10BaseT applications and network management tools on Fast Ethernet networks.

Gigabit Ethernet (IEEE 802.3Z)

Gigabit Ethernet builds on top of the Ethernet protocol but increases speed tenfold over Fast Ethernet to 1000 Mb/s, or 1 gigabit per second (Gb/s). Gigabit Ethernet allows Ethernet to scale from 10/100 Mb/s at the desktop to 100 Mb/s up the riser to 1000 Mb/s in the data center.



By leveraging the current Ethernet standard as well as the installed base of Ethernet and Fast Ethernet switches and routers, network managers do not need to retrain and relearn a new technology in order to provide support for Gigabit Ethernet. Cisco is leading the industry by driving the standards for Gigabit Ethernet while investing in products supporting Gigabit Ethernet, Gigabit Ethernet migration paths, and ATM.

Gigabit Ethernet over Copper (IEEE 802.3AB)

Gigabit Ethernet over Copper (also known as 1000BaseT) is an extension of the existing Fast Ethernet standard. It specifies Gigabit Ethernet operation over the Category 5e/6 cabling systems already installed, making it a highly cost-effective solution. As a result, most copper-based environments that run Fast Ethernet can also run Gigabit Ethernet over the existing network infrastructure in order to dramatically boost network performance for demanding applications.

10 Gigabit Ethernet

10 Gigabit Ethernet is basically a faster version of Ethernet. It uses the IEEE 802.3 Ethernet media access control (MAC) protocol, the IEEE 802.3 Ethernet frame format, and the IEEE 802.3 frame size. 10 Gigabit Ethernet is full duplex, just like full-duplex Fast Ethernet and Gigabit Ethernet; therefore, it has no inherent distance limitations. Because 10 Gigabit Ethernet is still Ethernet, it supports all intelligent Ethernet-based network services such as multi-protocol label switching (MPLS), Layer 3 switching, quality of service (QoS), caching, server load balancing, security, and policy-based networking. And it minimizes the user's learning curve by supporting familiar management tools and architectures. With a data rate of 10 Gb/s, 10 Gigabit Ethernet offers a low-cost solution to the demand for higher bandwidth in the LAN, MAN, and WAN. The potential applications and markets for 10 Gigabit Ethernet are enormous, including enterprises, universities, telecommunication carriers, and Internet service providers.

Wireless Ethernet (IEEE 802.11)

The acceptance and practicality of wireless communications between computers, routers or digital video devices is becoming so popular that manufacturers are forced to bring better and cheaper devices each time. After many years of proprietary products and ineffective standards, the industry has finally decided to back one set of standards for wireless networking: the 802.11 series from the Institute of Electrical and Electronics Engineers (IEEE). These emerging standards define ***wireless Ethernet***, or wireless LAN (WLAN), also referred to as ***Wi-Fi*** (Wireless Fidelity).

The main group of products belong to two main categories with data transfer speed of 11 Mb/s and 54 Mb/s, most of which are using the 2.4 GHz "free spectrum" range.

Since this is an emerging but very popular technology, we dedicate more space to wireless Ethernet at the end of this chapter.

Data speed and types of network cabling

By definition, Ethernet is a local area technology and works with networks that traditionally operate within a single building, connecting devices in **close proximity**. In the beginning coaxial cable was used for most Ethernet networks, but twisted pair, first Category 3, then Category 5 and Category 6 became the preferred medium for small LANs.

Ethernet uses a bus or star topography (or mix of the two) and supports data transfer rates of 10, 100, 1000, or 10,000 Mb/s. After the basic **10 Mb/s** data rate Ethernet (often called ***10BaseT*** when twisted pair cable is used), newer and faster standards were developed, notably the **100 Mb/s**, also known as ***Fast Ethernet***, the **1000 Mb/s**, also known as ***Gigabit Ethernet***, and, during the preparation of this book, ***10 Gigabit Ethernet*** which is near completion.

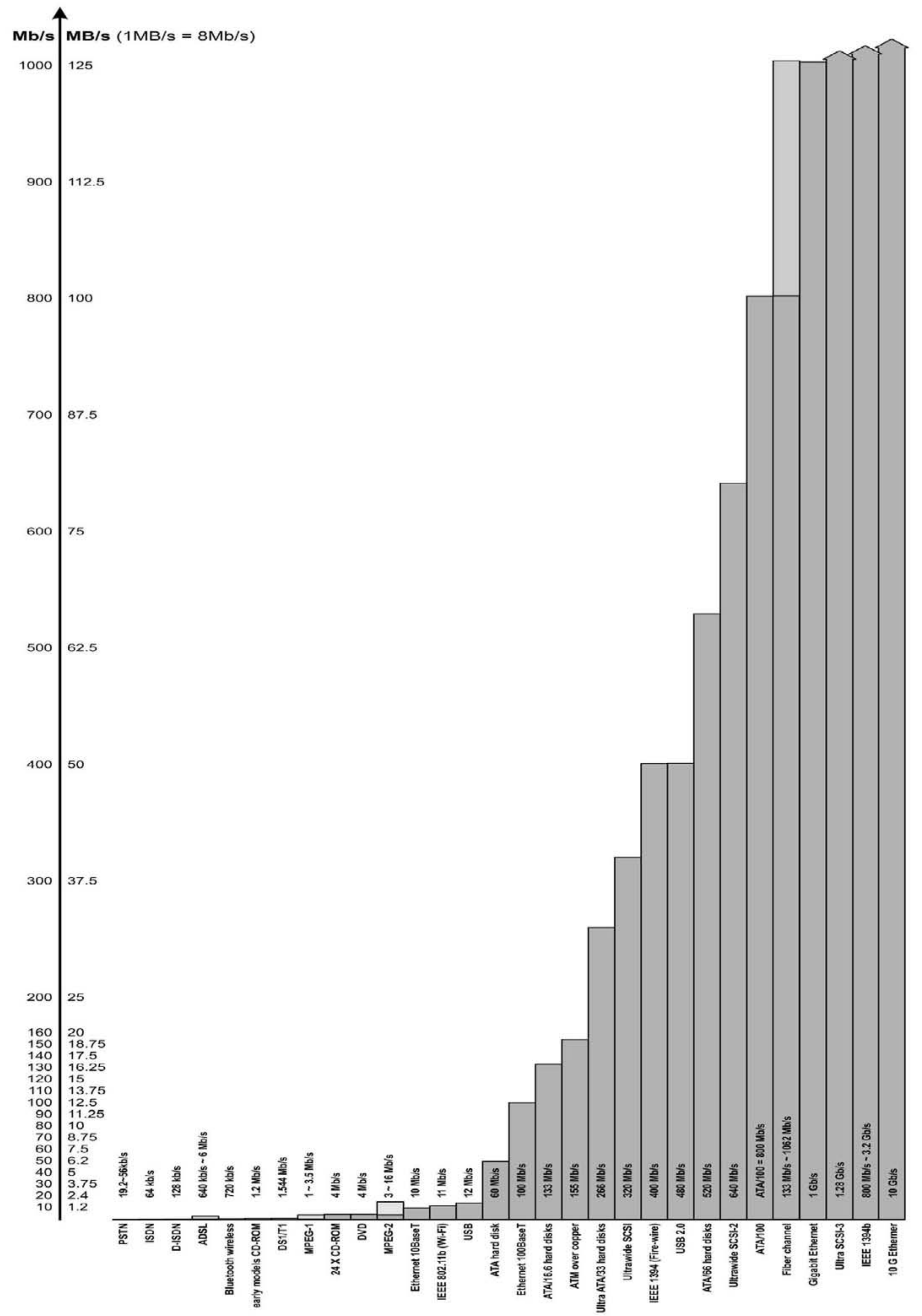
The Ethernet standard has grown to encompass new technologies as computer networking has matured, but the mechanics of operation for every Ethernet network today stem from Metcalfe's original design. The original Ethernet described communication over a single cable shared by all devices on the network. Once a device attached to this cable, it had the ability to communicate with any other attached device. **This allows the network to expand to accommodate new devices without requiring any modification to those devices already on the network.**

APPROXIMATE TIME NEEDED TO DOWNLOAD A FILE USING VARIETY OF DATA BANDWIDTHS (BEST CASE)

Data bandwidth / File size	56 kb/s (PSTN)	128 kb/s (2XISDN)	256 kb/s	512 kb/s	1 Mb/s
1 MB	2.5 min	1 min	32 s	16 s	8 s
10 MB	25 min	10 min	5 min	2.5 min	16 s
100 MB	4 hrs 10 min	1 hr 40 min	50 min	25 min	12.5 min
1 GB	1 day 18 hrs	16 hrs 66 min	8 hrs 33 min	4 hrs 17 min	2 hrs 9 min

The table above indicates the approximate time needed to download certain file size over a variety of data bandwidth media.

The graph on the next page illustrates the data bandwidth for various standard devices and standards.


Mb/s MB/s (1MB/s = 8Mb/s)
1000 125
900 112.5
800 100
700 87.5
600 75
500 62.5
400 50
300 37.5
200 25
160 20
150 18.75
140 17.5
130 16.25
120 15
110 13.75
100 12.5
90 11.25
80 10
70 8.75
60 7.5
50 6.2
40 5
30 3.75
20 2.4
10 1.2
PSTN 19.2~56kb/s
ISDN 64 kb/s
D-ISDN 128 kb/s
ADSL 640 kb/s ~ 6 Mb/s
Bluetooth wireless 720 kb/s
early models CD-ROM 1.2 Mb/s
DS1/T1 1.544 Mb/s
MPEG-1 1 ~ 3.5 Mb/s
24 X CD-ROM 4 Mb/s
DVD 4 Mb/s
MPEG-2 3 ~ 16 Mb/s
Ethernet 10BaseT 10 Mb/s
IEEE 802.11b (Wi-Fi) 11 Mb/s
USB 12 Mb/s
ATA hard disk 60 Mb/s
Ethernet 100BaseT 100 Mb/s
ATA/16.6 hard disks 133 Mb/s
ATM over copper 155 Mb/s
Ultra ATA/33 hard disks 266 Mb/s
Ultrawide SCSI 320 Mb/s
IEEE 1394 (Fire-wire) 400 Mb/s
USB 2.0 480 Mb/s
ATA/66 hard disks 520 Mb/s
Ultrawide SCSI-2 640 Mb/s
ATA/100 ATA/100 = 800 Mb/s
Fiber channel 133 Mb/s ~ 1062 Mb/s
Gigabit Ethernet 1 Gb/s
Ultra SCSI-3 1.28 Gb/s
IEEE 1394b 800 Mb/s ~ 3.2 Gb/s
10 G Ethernet 10 Gb/s

One of the most common questions in CCTV today is how quick an image update is over a network or how long a download of certain footage will take.

In order to be able to understand and calculate this the readers should be reminded that there is a difference between bits (marked with the lower case "b") and Bytes (marked with capital "B"). Typically, **there are 8 bits in one Byte**. Therefore, when making a rough calculation as to how long it would take to download a file over a particular data link connection, the Mb/s data transfer rate needs first to be converted to MB/s by dividing it by 8; also, allowance should be made for traffic collision losses and noise, which could vary anywhere from 10 to 50%. So in many worst case scenario calculations, 50% of the data transfer rate should be used.

For example, if we have a dial-up Internet connection with a typical modem of 56 kb/s, the maximum transfer rate will be around 6 to 7 kB/s, as the best, and around 3 kB/s as the worst case scenario. With a dial-up PSTN connection, we still use analog modulation techniques, the quality of which can vary greatly, depending on the line noise, distance and hardware quality, so it is possible that the worst case scenario can be even lower than 3 kB/s. So, when using 56 kb/s modem, there is no guarantee that the established connection will be 56 kb/s, but that represents the maximum achievable data transfer rate when conditions are excellent. Going back to our example, if we have for example, a 1 MB file to download, it would take at least 150 seconds (1024 Bytes divided by 6 kB/s) when good-quality PSTN dial-up connection is used. For the same file to be transferred over an ADSL Internet connection of 512 kb/s, it would take much faster, but at least 16 seconds (512 kb/s = 64 kB/s; 1024 kB divided by 64 kB = 16 sec) and can go up to 32 seconds, if equipment and lines are of low quality. This is still much faster compared to over 2.5 minutes for a 56 kb/s PSTN modem connection.

In calculations as illustrated here, consideration should be given to the fact that the speed of download of a file is as fast as the slowest speed in the chain. This means that if a computer you download from has a limited upload speed which is much lower than your download speed, then that will define your download time.

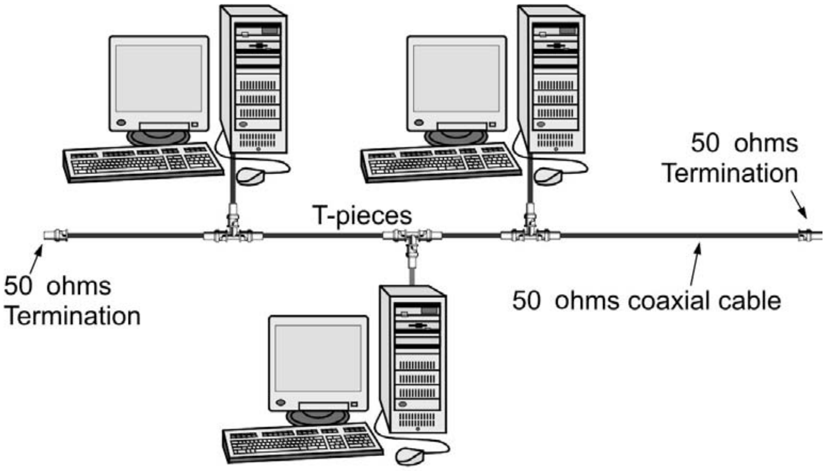
The same principles of data speed calculations apply to a variety of network communication and storage devices. Each component in a computer and a network has its own limitation imposed by the component. This is a very important consideration especially in the modern CCTV digital system designs where there is an ever growing need for faster transmission, more cameras recorded, and more pictures per second required.

All components in such a chain of video streaming influence the total performance result. The network is not always the bottleneck. If, for example, we have a Gigabit Ethernet in place (with matching network cards and network switchers or routers), it is quite possible that a computer we have as a video recorder uses ATA66 hard drives (peaking at 520 Mb/s) which is slower than the network itself, and as such becomes a bottleneck in playing back multiple cameras on multiple operators' consoles.

Being aware of the totality of a digital networked system and of each single component making such system is the key to a successful implementation of this new technology we have embraced in CCTV.

Ethernet over coax and UTP cables

The Ethernet coaxial cable uses 50 ohms impedance and cable (RG-58), as opposed to 75 ohms for analog video (RG-59). Since they are very similar in size and use very similar BNC connectors, care should be taken that these not be mixed. When using Ethernet coaxial cables, correct terminations are as important, if not more so, as in analog video. If a network is configured in a bus topology using coaxial cable, both ends of such a bus have to be terminated with 50 ohms. The networking with coaxial cables is also known as ***unbalanced transmission***, as is the case with the analog CCTV video signals, whereas the ***unshielded twisted pair*** (UTP) is known as ***balanced***. Coaxial networking offers longer distances with no repeaters, but balanced transmission has other important advantages over unbalanced mostly in eliminating external electromagnetic interferences using the ***common mode rejection*** principles (as in twisted pair video).



Ethernet LAN using coaxial cable

"Balanced" relates to the physical geometry and the dielectric properties of a twisted pair of conductors. If two insulated conductors are physically identical to one another in diameter, concentricity, and dielectric material, and are **uniformly twisted with equal length of conductor**, then the pair is **electrically balanced** with respect to its surroundings.

The degree of electrical balance depends on the design and manufacturing process. **For balanced transmission, an equal voltage of opposite polarity is applied on each conductor of a pair.** The electromagnetic fields created by one conductor **cancel out** the electromagnetic fields created by its "balanced" companion conductor, leading to very little radiation from the balanced twisted pair transmission line. **The same concept applies to external noise that is induced on each conductor of a twisted pair.**

A noise signal from an external source, such as radiation from a radio transmitter antenna, generates an equal voltage of the same polarity, or "common mode voltage," on each conductor of a pair. The difference in voltage between conductors of a pair from this radiated signal (the "differential voltage") is effectively zero.

Since the desired signal on the pair is the differential signal, the interference practically does not affect balanced transmission.

The degree of electrical balance is determined by measuring the "differential voltage" and comparing it to the "common mode voltage" expressed in decibels (dB). When good network interface equipment, quality cables and high-quality termination are used, the Cat-5 and Cat-6 are easier to prepare and offer

good-quality networking. This is why the “Cat” networking makes up the majority of LANs today.

The term Cat to classifications of UTP (unshielded twisted pair) cables. The difference in classifications of the cables is based mainly on the bandwidth, copper type, size and electrical performance. Currently, the most popular are the main Categories of cable – Category 3, 4, 5, 5e, and 6, all of which are defined by the Electronic Industry Association (EIA) and the Telecommunications Industry Association (TIA) recommendations.

The EIA/TIA defines the following five categories of twisted pair cable:

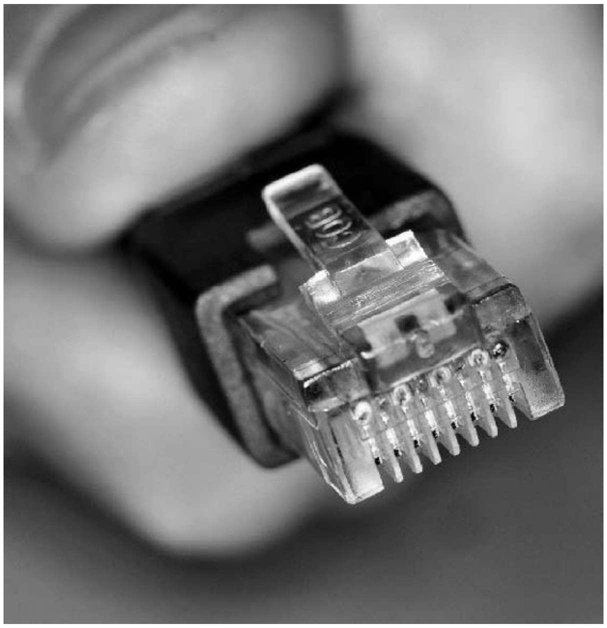
• Cat-1 – Traditional telephone cable

• Cat-2 – Cable certified for data transmissions up to 4 Mb/s

• Cat-3 – Balanced 100 ohm cable and associated connecting hardware whose transmission characteristics are specified up to 16 MHz. It is used by 10BaseT and 100BaseT4 installations. Category 3 is the most common type of previously installed cable found in corporate wiring schemes, and it normally contains four pairs of wire.

• Cat-4 – Balanced 100 ohm cable and associated connecting hardware whose transmission characteristics are specified up to 20 MHz. It is used by 10BaseT and 100BaseT4 installations. The cable normally has four pairs of wire. This grade of UTP is not common.

• Cat-5 – Balanced 100 ohm cable and associated connecting hardware whose transmission characteristics are specified up to 100 MHz. It is used by 10BaseT, 100BaseT4, and 100BaseTX installations.

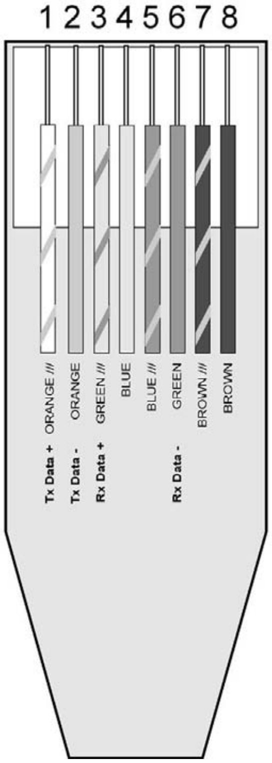


An RJ-45 connector

The Cat-5 10/100 Ethernet cables have 8 wires, of which 4 are used for data. The other wires are twisted around the data lines for electrical stability and resistance to electrical interference. The cable termination (connector) is known as RJ-45 and resembles a large telephone line connector.

Electrical signals propagate along a cable very quickly (typically 65% of the speed of light), but even for digital signals, as is the case with analog, the same electrical laws apply – they **weaken** as they travel, and **electrical interference** from neighboring electromagnetic devices **affects the signal**. The effects of voltage drop, combined with the effect of inductance and capacitance for high-frequency signals (high bit rate) and external electromagnetic interferences, impose physical limitations on how far a certain cable can carry data before it gets to a repeater (switch or





A typical RJ-45 pin layout as per the EIA T-568 standard (view from the contacts side)

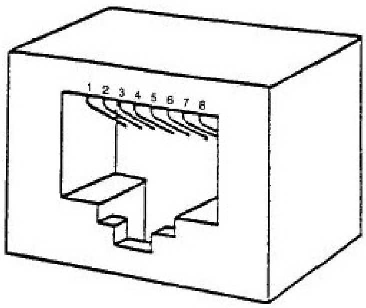
router). A network cable must be short enough that devices at opposite ends can receive each other's signals clearly and with minimal delay. This places a **distance limitation** on the maximum separation between two devices. This is called **network diameter** of the Ethernet network.

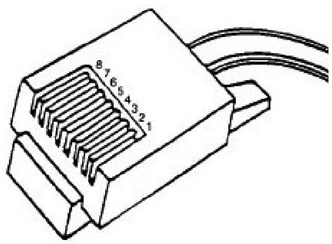
Limitations apply for other Ethernet media as well, such as wireless or fiber optic, although the minimum distances are different from copper.

The most common network cable, Cat-5, uses AWG24 wires (with approximate diameter of 0.2 mm^2) and has 100 ohm impedance. Readers are reminded that AWG (***American Wire Gauge***) is a system that specifies wire size. The gauge varies inversely with the wire diameter size, which defines the electrical resistance (the smaller the AWG number, the larger the conductor diameter, the smaller the resistance).

Twisted pair cable comes in two main varieties, solid and stranded. Solid cable supports longer runs and works best in fixed wiring configurations like office buildings. Stranded cable, on the other hand, is more pliable and better suited for shorter-distance, movable cabling such as "patch" cables.

A variation on Cat-5, called ***Cat-5e***, **is even better performing network cable**. It was ratified in 1999, formally called ANSI/TIA/EIA 568A-5, or simply Category 5e (the e stands for **enhanced**). Cat-5e is also 100 ohm impedance cable and is completely backward compatible with the Cat-5 equipment. **The enhanced electrical performance of Cat-5e ensures that the cable will support applications that require additional bandwidth, such as gigabit Ethernet or analog video (if used in twisted pair video transmission)**.





Cat-5e has an incremental improvement designed to enable cabling to support full-duplex Fast Ethernet operation and Gigabit Ethernet. The main differences between Cat-5 and Cat-5e can be found in the specifications where performance requirements have been raised slightly.

While Cat-5 components may function to some degree in a Gigabit Ethernet (at shorter distances), they perform below standard during high data transfer scenarios. Cat-5e cables work better with gigabit speed products. So, when using a 100 Mb/s switch it is better to get Cat-5e cable instead of Cat-5.

The next level in the cabling hierarchy is Category 6 (ANSI/TIA/EIA-568-B.2-1), which was ratified by the EIA/TIA in June 2002. **Cat-6 provides higher performance than Cat-5e and features more stringent specifications for crosstalk and system noise.**

Also built to have 100 ohm impedance, Cat-6 cable requires a greater degree of precision in the manufacturing process compared to Cat-5. Similarly, a Cat-6 connector requires a more balanced circuit design. Cat-6 provides higher performance than Cat-5e and features **more stringent specifications for crosstalk and system noise**.

All Cat-6 components are backward compatible with Cat-5e, Cat-5, and Category 3.

The quality of the data transmission depends upon the performance of the components of the channel. So to transmit according to Cat-6 specifications, connectors, patch cables, patch panels, cross-con-

CATEGORY CABLES TYPICAL SPECIFICATIONS

	Cat-3	Cat-5	Cat-5e	Cat-6	Cat-7
Impedance	100 Ω	100 Ω	100 Ω	100 Ω	100 Ω
NEXT (Near End Cross Talk)	29 dB	32.3 dB	35.3 dB	44.3 dB	62.1 dB
Bandwidth	16 MHz	100 MHz	100 MHz	250 MHz	600 MHz
Typical use	up to 10 Base-T	up to 100 Base-T Fast Ethernet	up to 1 Mb/s Gigabit Ethernet	up to 1 Mb/s Gigabit Ethernet	up to 1 Mb/s Gigabit Ethernet

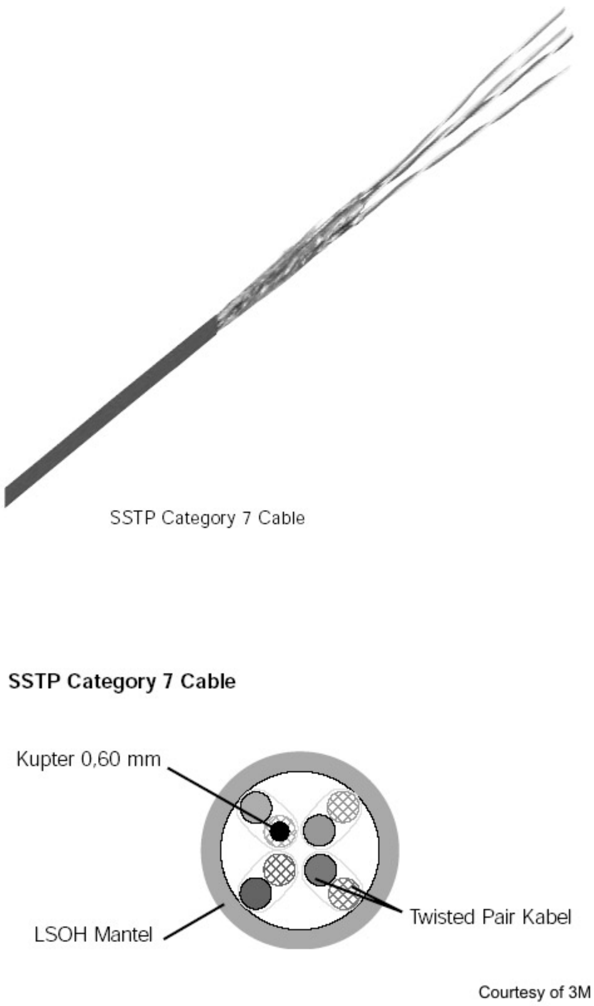
This table shows typical Category Unshielded Twisted Pair specifications.

nects, and cabling must all meet Cat-6 standards. The channel basically includes everything from the wall plate to the wiring closet. The Cat-6 components are tested both individually and together for performance. In addition, the standard calls for generic system performance so that Cat-6 components from any vendor can be used in the channel. Cat-6 channel transmission requirements should result in a Power-Sum Attenuation-to-Crosstalk Ratio (PS-ACR) that is greater than or equal to zero at 200 MHz. In addition, all Cat-6 components must be backward compatible with Cat-5e, Cat-5, and Category 3. If different category components are used with Cat-6 components, then the channel will achieve the transmission performance of the lower category. For instance, if Cat-6 cable is used with Cat-5e connectors, the channel will perform at a Cat-5e level.

Cat-6 cable contains four pairs of copper wire and, unlike Cat-5, utilizes all four pairs; the communication speed it supports is more than twice the speed of Cat-5e. **As with all other types of twisted pair EIA/TIA cabling, Cat-6 cable runs are limited to a maximum recommended run rate of 100 m (approximately 328 ft).**

Because of its improved transmission performance and superior immunity from external noise, systems operating over Category 6 cabling will have fewer errors than Category 5e for current applications. This means fewer re-transmissions of lost or corrupted data packets under certain conditions, which translates into higher reliability.

The “fastest” copper cable currently covered by the EIA/TIA standards is the Category 7 targeting Gigabit networks, which is still under development. Cat-7 is supposed to be fully compatible with previous standards. The Cat-7 is no longer unshielded. The specification requirements are so high that each pair has to be shielded, and in addition all four pairs have to be shielded again, making the Cat-7 the most expensive Cat cable. Also, Cat-7 no longer uses RJ-45 connectors. Many users will argue that fiber optics is a better choice once you see a need for such a high-performance network cable, so we will leave this categorization for further reading elsewhere in more up-to-date books and manuals, but readers should be aware that new cable categories have been developed.



Cat-7 cable description

Patch and crossover cables

Two kinds of wiring schemes are available for Ethernet cables: **patch** and **crossover** cables.

Patch cables are used for connecting computers using hubs or switches (sometimes referred to as straight cable).

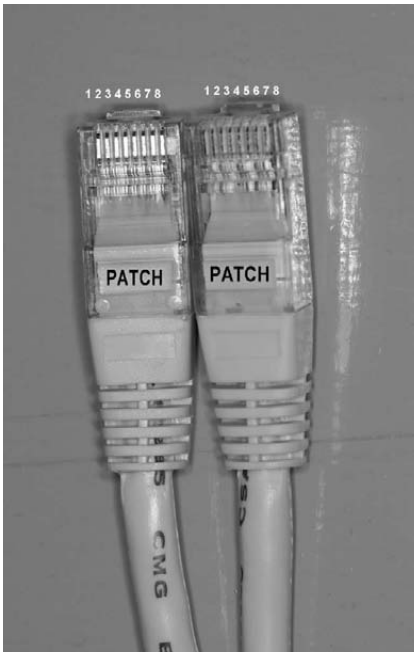
The crossover cables are normally used to connect two PCs without the use of a hub, or can be used to cascade two hubs without using an uplink port.

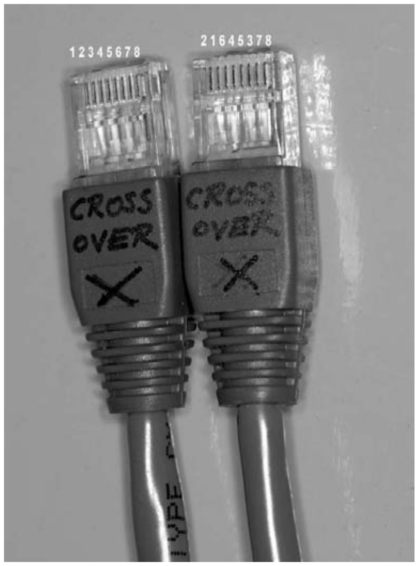
A crossover cable is a segment of cable that crosses over pins 1&2 and 3&6, which the Tx and Rx pins in order to be able to have two computers exchange information. If a cable does not say crossover, it is a standard patch cable.

If you are not sure what type of cable you have, you can put the two RJ-45 connectors next to each other from the same side (as shown on the photos here) and **if the wiring colors are in identical order from left to right, then it is a patch cable**. **If pins 1&2 have reversed color wires order, then it is a crossover**. A good practice is to always have the crossover cable color different from the color of the majority of the patch cables used – for example, a yellow crossover cable amongst blue-colored patch cables.

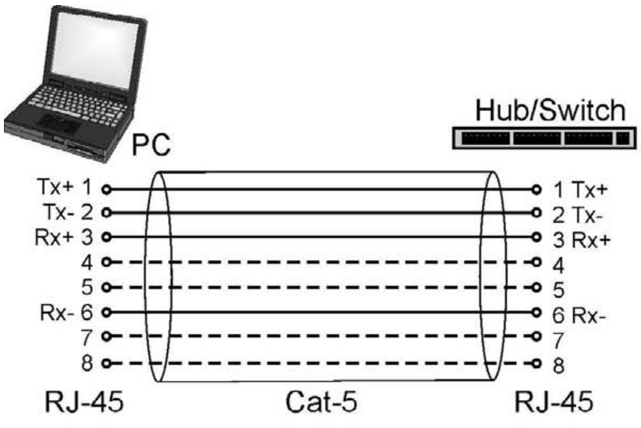
Stranded cable, as opposed to solid core, has several small gauge wires in each separate insulation sleeve. Stranded cable is more flexible, making it more suitable for patch cords. When using **patch cables,** the **recommended maximum lengths are around 10 m** (30 ft). This construction is great for the flexing and the frequent changes that occur at the wall outlet or patch panel. **The stranded conductors do not transmit data signals as far as solid cable**. The EIA/TIA 568A standard limits the length of patch cables to 10 meters in total length. It does not mean you cannot use stranded cable for longer runs; it is just not recommended. Some installations have stranded cable running over 30 meters with no problems, but care should be taken not to use stranded cable in larger installations.

Solid copper cable has one larger gauge wire in each sleeve. Solid cable has **better** electrical performance than stranded cable and is traditionally used for inside walls and through ceilings, or any type of longer run of cable. **All such Category network cables (using solid core) are specified for a maximum length of around 100 m (328 ft) before a repeater is needed**.

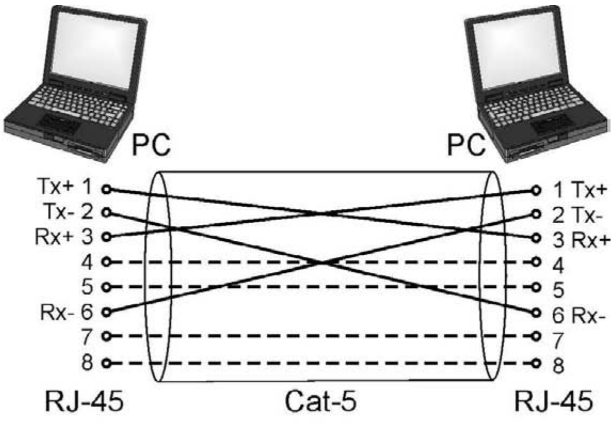




Patch and crossover

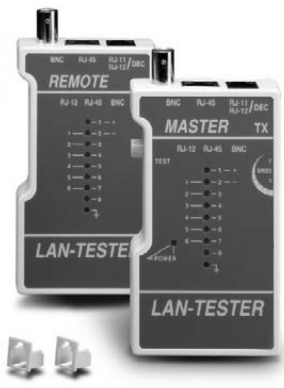


STRAIGHT CAT-5 CABLE



CROSSOVER CAT-5 CABLE

This is not to say that longer distances are not possible, but this very much depends on the cable quality and the intended network bandwidth. For example, if Cat-6 cable is used for up to 100 Mb/s, then longer distances than 100 m can be achieved since Cat-6 is very stringent in its design and it targets the Gigabit network speeds. How much longer the cable can be run without a repeater (router/switch) can only be proven by test.



LAN cable tester

A variety of expensive and cheaper tools are available to verify the patch or crossover cable quality, and it is recommended that every network cable installer should have at least the basic one.

One of the main sources of problems for any copper cabling, including the "Cat" types of cable, are the ***electromagnetic interferences***. Electromagnetic interferences (EMIs) are potentially harmful to your communications system because they can lead to signal loss and degrade the overall performance of high-speed Cat cabling. EMI interference in signal transmission or reception is caused by the radiation of electrical or magnetic fields which are present nearby all power cables, heavy electric machinery, or fluorescent lighting.



courtesy of ABM Communications

A variety of RJ-45 crimping tools are available.

This is unfortunately the nature of electrical current flowing through copper cable, and it is the basics of electromagnetic interdependence. We say "unfortunately" in this

case, when discussing the unwanted interference to signal cables, but in fact the same concept is used for generating electric power and moving electric motors, in which case the EMI (read it as *electro-magnetic inductance* in such case) is a highly desirable effect.

Avoiding EMI is as simple as not laying the network cable within 30 cm (1 ft) of electrical cable, or, if needed, switching from UTP to more expensive shielded cable. These are basic rules that should be applied at all times.

The only time EMI is not an issue is when using fiber cables. This is simply because fiber does not conduct electricity but uses light as a transmission media. All longer distance and wider bandwidth communications are usually achieved with fiber cables, for they offer not only longer distances (a couple of kilometers) but much wider bandwidth. Most importantly, they are not subject to EMI.

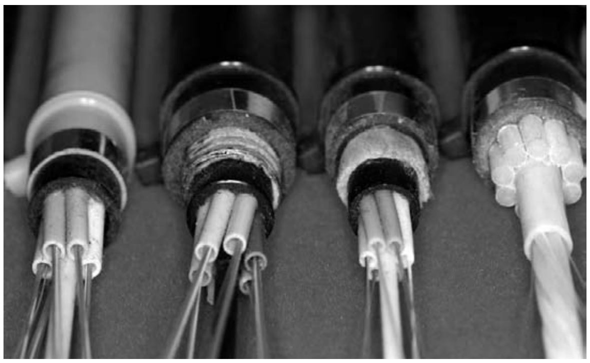
Fiber optics network cabling

As was the case in analog video transmission, fiber optics has some significant technological advantages over copper.

Fiber optics can transmit wider bandwidth data and longer distances than copper.

This means less equipment and infrastructure (such as switches and wiring cabinets) is needed, thereby lowering the overall cost of the LAN. Fiber optics is physically much thinner and more durable than copper, taking up less space in cabling ducts and allowing for a greater number of cables to be pulled through the same duct. New developments in fiber optics cabling also allow it to be tied in a knot and still function normally. As described under the analog video transmission over fiber section in Chapter 10, fiber optics completely encloses the light pulses within the outer sheath, making it impervious to outside interference or eavesdropping.

Another very important property **of fiber optic is its immunity to any electromagnetic interference, including lightning induction**. You can submerge it in water, and it is less susceptible to temperature fluctuations than copper. All these qualities make fiber optics cable the ultimate choice.



Various types of fiber cables

Fiber provides higher bandwidth (approximately 50 Gb/s, that is 50 gigabits per second, over multi-mode and even higher over single-mode fiber), and it “future proofs” a network’s cabling architecture against copper upgrades.

Although users currently do not require speeds faster than Fast Ethernet in small to medium-size CCTV projects, the cost differential between copper and fiber optics will become less and less significant, making fiber optics a compelling option for any size system. Fiber optics infrastructures are still more expensive

than copper. Fiber optics switch ports and adapter cards cost, on average, approximately 50% more than comparable copper products. However, when you factor in the cost savings associated with fiber (such as the need for fewer repeaters and switches, wider bandwidth), the overall cost of a fiber optics system drops comparable to one with a copper-based LAN.

When you eliminate the expense of creating and maintaining extra wiring cabinets, a fiber optics LAN costs about the same, or even less, than a copper LAN. In the past, fiber optics' lofty price had little to do with the medium itself – most of the expense lay in transceivers and connectors. Due to new products in each of these areas, costs have been decreasing, pushing fiber optics use upward.



ST connectors

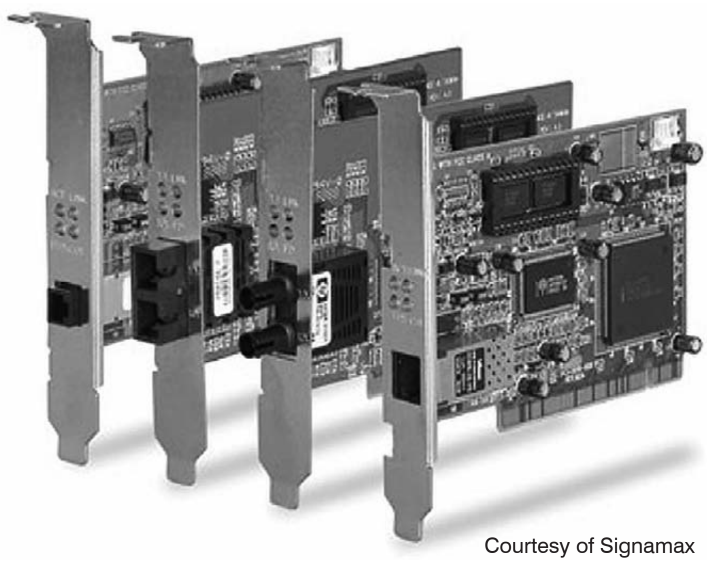


SC connectors



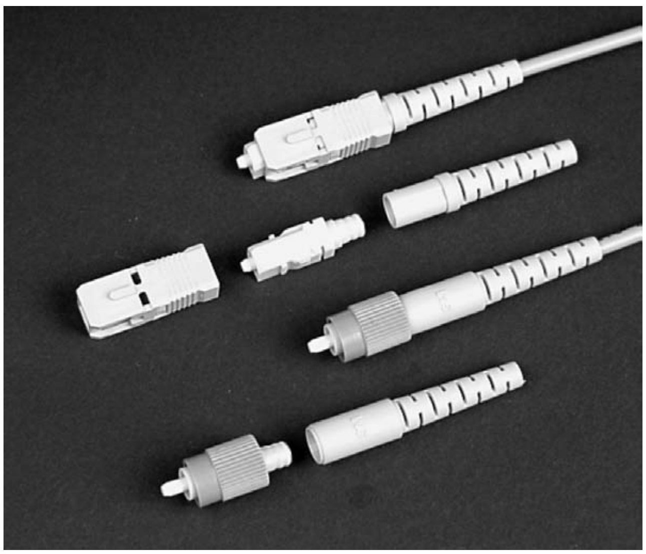
MTRJ connectors

Maximum distances achievable with a single run of fiber depends on the type of fiber (multi-mode or single-mode) as well as the transmitting and receiving equipment. The accurate distances can only be found after testing an installation with an OTDR (***Optical Time Domain Reflectometer***), which will naturally consider the quality of terminations, cable, and equipment.



Courtesy of Signamax

Various types of fiber network interface cards



Courtesy of 3M

Various types of fiber network connectors

A general rule of thumb is that multi-mode will go up to 2 km, and single-mode usually over 20 km without the need for repeaters.

Because of the high bandwidth and distances it can handle, fiber optics is most often used as a network backbone, where more network segments are connected in a larger network, typical for the digital CCTV systems of casinos and large shopping centers. In such system design, fiber to copper media converters are used. Many different makes and models are available on the market; they can be stand alone, or multiple converters can be housed in 19” racks.

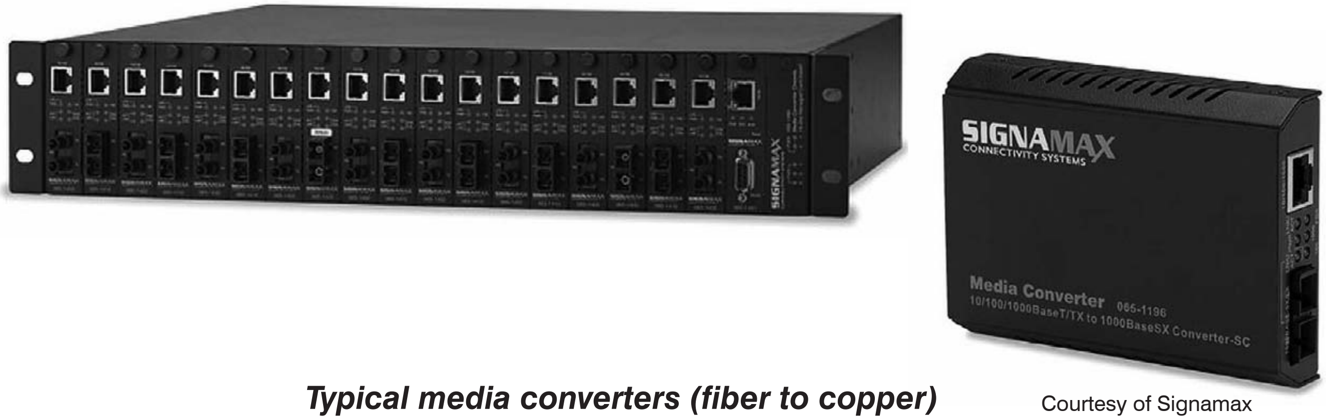
It is important here to highlight here again the importance of proper tools for testing and fault-finding fiber networks. If you consider fiber networks a serious part of your CCTV business, investing in good-quality instruments and tools is always a wise thing to do. If, however, this is beyond the reach of your budget, you can always hire specialized fiber optics businesses that can perform most of the tasks on your behalf. If the fiber cable is already installed, they would typically charge per fiber connection termination, which would include an OTDR report.



Courtesy of Fluke

With proper tools everything is known – OTDR for networks.

We have already explained and described a few fiber cable termination methods in this book, under the analog video transmission media. This technology gets better and easier to terminate fiber cables, details of which can be found from the manufacturers, so we are not going to go into details here, but we shall concentrate on the Ethernet basics and components.



Typical media converters (fiber to copper)

Courtesy of Signamax

Network concepts and components

Ethernet networking follows a simple set of rules and components that govern its basic operation.

The Ethernet basically uses the CSMA/CD access method to handle simultaneous demands. It is one of the most widely implemented LAN standards. The acronym **CSMA/CD** signifies ***carrier-sense multiple access with collision detection*** and describes how the Ethernet protocol regulates communication among nodes. Although the term may seem intimidating, if we break it apart into its component concepts we will see that it describes rules very similar to those that several people use in polite conversation. If one talks at the dinner table, for example, the other listens until he or she stops talking. In the moments of silence when somebody decides to say something, the rest of the listeners wait again until the second person finishes talking. If in the moments of pause two or more people start to talk simultaneously, a collision occurs. In networking, this is equivalent to data collision between two computers. The CSMA/CD protocol states that in such cases both computers maintain silence briefly and wait a **random** time until they start talking again. Whichever randomness is shorter becomes the first "speaker" of the two and the others wait until he or she finishes. **The random time gives all participants (computer stations) an equal chance in the conversation (data exchange) at the dinner table (Ethernet network) to have their say.**

To better understand these rules and components, it is important to understand the basic terminology, so here we are going to introduce the most common ones, with a short description of what they mean.

This book is intended for the CCTV industry, and as such the Ethernet basics are somewhat condensed. Readers interested in more details are referred to more extensive books dedicated to networking, such as *Internetworking Technologies Handbook*, published by Cisco Systems.

- ***Network*** – A network is a group of computers connected together in a way that allows information to be exchanged between the computers.

- ***Local Area Network*** **(LAN)** – A LAN is a network of computers that are in the same general physical location, usually within a building or a campus. If the computers are far apart (such as across town or in different cities), then a Wide Area Network (WAN) is typically used.

- ***OSI layers*** – An Open System Interconnection reference model was introduced by ISO, which defines seven layers of networking.

- ***Node*** – A node is anything that is connected to the network. Although a node is typically a computer, it can also be something like a printer or a DVR.

- ***Segment*** – A segment is any portion of a network that is separated from other parts of the network by a switch, bridge, or router.

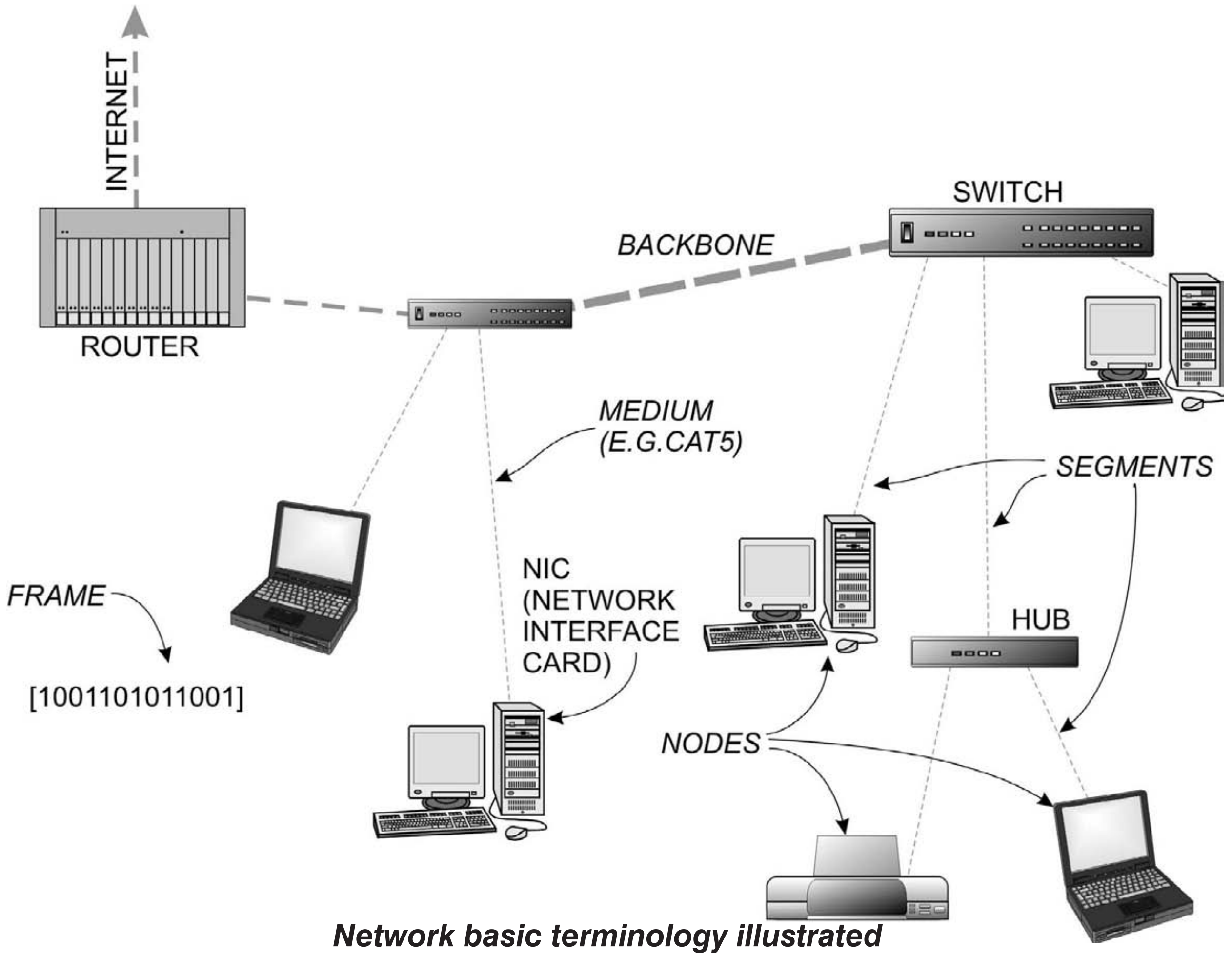
- ***Backbone*** – The backbone is the main cabling of a network to which all of the segments are connected. Typically, the backbone is capable of carrying more information than the individual

segments. For example, each segment may have a transfer rate of 10 Mb/s (megabits per second), whereas the backbone may operate at 100 Mb/s.

• ***Repeater*** – Repeater is a network device used to extend and interconnect network segments allowing for longer distances. Repeaters receive signals from one network segment and amplify, re-time, and re-transmit those signals to another network. They are very similar to the in-line amplifiers we have in the analog CCTV. There are limits to how many repeaters can be used one after another. Repeaters are not capable of performing complex filtering or routing that other devices listed below are.

• ***Hub*** – The hub connects multiple computers and devices into a LAN. Hubs work in the physical layer 1 of the OSI model (explained further in the book) and connects each computer via a dedicated cable. Hubs do not perform any "intelligent" data packet switching or routing; thus, hubs with many ports will cause more data collisions and losses. Hubs basically create physical star networks, and in some respect they can be considered as repeaters.

• ***Bridge*** – Bridge is a more "intelligent" data communication device that connects and enables data packet forwarding between homogeneous networks. Bridges support store-and-forward traffic switching. Bridging occurs at level 2 of the OSI model (explained further in this chapter).



Network basic terminology illustrated

• ***Switch*** – A network switch is another “intelligent” data communication device that is more common and a successor to the network bridge. While bridges have only a few ports, switches handle many more. Switches also reduce data collision in the network segments it connects, and it provides dedicated bandwidth to each network segment.

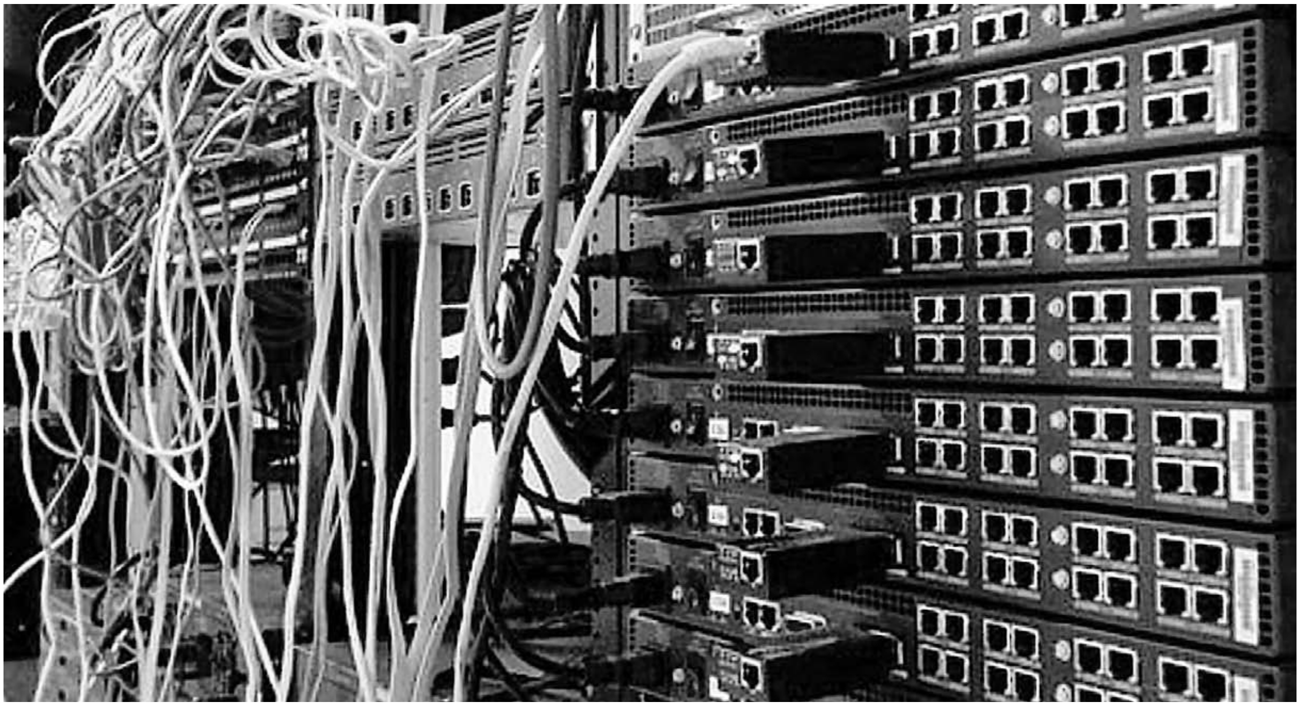
• ***Router*** – Routers are specialized computers that send messages to their destinations along thousands of pathways. They have even higher “intelligence” than switches as they are crucial devices that let messages flow between networks, rather than within networks. Routing is often compared and thought to be the same as bridging, but the main difference is that routing is “more intelligent” as it is based on the router knowing and learning the shortest path to deliver a specific information from source to destination. Routing occurs at level 3 of the OSI model.

• ***Network Interface Card* (NIC)** – Every computer (and most other devices) is connected to a network through an NIC. In most computers, this is an Ethernet card (normally 10 or 100 Mb/s) that is plugged into a PCI slot on the computer’s motherboard.

• ***Media Access Control* (MAC) *address*** – This is the physical address of any device – such as the NIC in a computer – on the network. The MAC address, which is made up of two equal parts, is 6 bytes long. The first 3 bytes identify the company that made the NIC; the second 3 are the serial number of the NIC itself.

• ***Unicasting*** – A unicast is a transmission from one node addressed specifically to another node.

• ***Multicasting*** – In a multicast, a node sends a packet addressed to a special group address.



Network switches

Devices that are interested in this group register to receive packets addressed to the group. An example might be a router sending out an update to all of the other routers.

• ***Broadcasting*** – In a broadcast, a node sends out a packet that is intended for transmission to all other nodes on the network.

• ***Data Frames*** – Frames are analogous to sentences in human language. In English, we have rules for constructing our sentences: We know that each sentence must contain a subject and a predicate. The **Ethernet protocol** specifies a set of rules for constructing frames. There are explicit minimum and maximum lengths for frames, and a set of required pieces of information that must appear in the frame. Each frame must include, for example, both a **destination address** and a **source address**, which identify the recipient and the sender of the message.

Networking software

The Internet protocols

In order for various computers to talk to each other via any network, there must be a common language of understanding, a common protocol. In networking, the term **protocol** refers to a set of rules that govern communications. Protocols are to computers what language is to humans. Since this book is in English, to understand it you must be able to read English. Similarly, for two devices on a network to communicate successfully, they must both understand the same protocols.

Various protocols belonging to layers 5, 6, and 7, are used in today's world of the Internet, and this book would not be complete without listing all of them and describing them briefly.

TCP/IP – Transmission Control Protocol / Internet Protocol

Two of the most popular suites of protocols used in the Internet today. Introduced in the mid-1970s by Stanford University and Bolt Beranek and Newman (BBN) after funding by DARPA (Defence Advanced Research Projects Agency). First appeared under the Berkeley Software Distribution (BSD) Unix.

TCP is reliable; that is, packets are guaranteed to wind up at their target, in the correct order.

IP is the underlying protocol for all the other protocols in the TCP/IP protocol suite. IP defines the means to identify and reach a target computer on the network. Computers in the IP world are identified by unique numbers, which are known as IP addresses (explained further in this chapter).

PPP – Point-to-Point Protocol

A protocol for creating a TCP/IP connection over both synchronous and asynchronous systems. PPP provides connections for host to network or between two routers. It also has a security

mechanism. PPP is well known as a protocol for connections over regular telephone lines using modems on both ends. This protocol is widely used for connecting personal computers to the Internet.

SLIP – Serial Line Internet Protocol

A point-to-point protocol to be used over a serial connection, a predecessor of PPP. There is also an advanced version of this protocol known as CSLIP (***Compressed Serial Line Internet Protocol***) which reduces overhead on a SLIP connection by sending just a header information when possible, thus increasing packet throughput.

FTP – File Transfer Protocol

A protocol that enables the transfer of text and binary files over a TCP connection. FTP allows for files transfer according to a strict mechanism of ownership and access restrictions. It is one of the most commonly used protocols over the Internet today.

Telnet

A terminal emulation protocol, defined in RFC854, for use over a TCP connection. It enables users to log in to remote hosts and use their resources from the local host.

SMTP – Simple Mail Transfer Protocol

A protocol dedicated for sending e-mail messages originating on a local host over a TCP connection to a remote server. SMTP defines a set of rules that allows two programs to send and receive mail over the network. The protocol defines the data structure that would be delivered with information regarding the sender, the recipient (or several recipients), and, of course, the mail's body.

HTTP – Hyper Text Transport Protocol

A protocol used to transfer hypertext pages across the World Wide Web.

SNMP – Simple Network Management Protocol

A simple protocol that defines messages related to network management. Through the use of SNMP, network devices such as routers can be configured by any host on the LAN.

UDP – User Datagram Protocol

A simple protocol that transfers packets of data to a remote computer. UDP does not guarantee that packets will be received in the same order they were sent. In fact, it does not guarantee delivery at all.

ARP – Address Resolution Protocol

In order to map an IP address into a hardware address the computer uses the ARP protocol which broadcasts a request message that contains an IP address, to which the target computer replies with both the original IP address and the hardware address.

NNTP – Network News Transport Protocol

A protocol used to carry USENET posting between News clients and USENET servers.

The OSI seven-layer model of networking

The basics of networking revolves around understanding the so-called seven-layer OSI model. Proposed by the ISO (International Standards Organization) in 1984, the OSI acronym could be read as ISO backwards, but it actually means Open System Interconnection reference model.

The OSI model describes how information from a software application in one computer moves through a network medium to a software application in another computer. The OSI model is considered the primary architectural model for intercomputer communications.

The idea behind such a model is to simplify the task of moving information between networked computers and make it manageable. A task, or group of tasks, is then assigned to each of the seven OSI layers. Each layer is reasonably self-contained, so that the tasks assigned to each layer can be implemented independently.

OSI has two major components:

- An abstract model of networking (the Basic Reference Model, or seven-layer model)
- A set of concrete protocols

Parts of OSI have influenced Internet protocol development, but none more than the abstract model itself, documented in OSI 7498 and its various addenda. In this model, **a networking system is divided into layers**. Within each layer, one or more entities implement its functionality. Each entity interacts directly only with the layer immediately beneath it, and provides facilities for use by the layer above it. Protocols enable an entity in one host to interact with a corresponding entity at the same layer in a remote host.

The seven layers of the OSI Basic Reference Model are (from bottom to top):

Layer 7 – Application

Layer 6 – Presentation

Layer 5 – Session

Layer 4 – Transport

Layer 3 – Network

Layer 2 – Data link

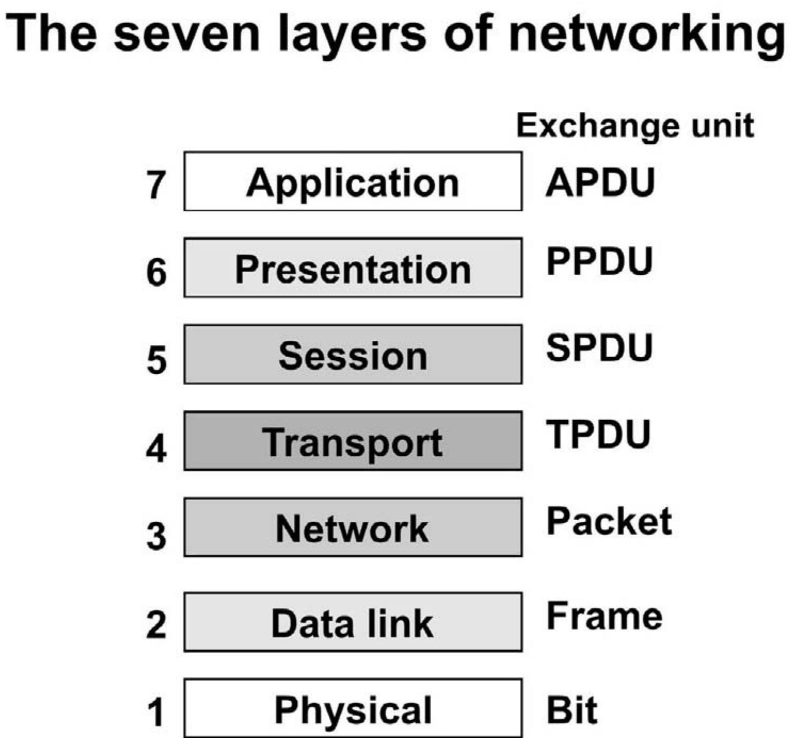
Layer 1 – Physical

Many prefer to list the seven layers starting from layer 1 down to layer 7, but it does not really matter, as long as they are remembered as the basic building blocks of the whole networking technology. A handy way to remember the layers is the sentence "*All people seem to need data processing*" and each first letter of that sentence corresponds to the first letter of the layers starting from layer 7 going to layer 1.

The seven layers can be grouped into two main groups: ***upper layers*** and ***lower layers***.

The upper layers of the OSI model deal with application issues and **generally are implemented in software only**. Layer 7 is the closest to the computer user as it represents the software application passing the information to the user. Basically, both the user and the application layer processes interact with software application that contains a communication component.

As we go down through the layers, we get closer to the physical medium. So, the lower layers of the OSI are closer to the hardware (although do not exclude software) and handle the data transport issues. **The lowest layer is closest to the physical medium, that is, network cards and network cables, and they are responsible for actually placing information on the network medium.**



Let us now explain the meaning of each layer, starting from the lowest one.

1. The Physical layer

The Physical layer describes the physical properties of the various communications media, as well as the electrical properties and interpretation of the exchanged signals. For example, this layer defines the size of Ethernet cable, the type of connectors used, and the termination method.

The Physical layer is concerned with transmitting raw bits over a communication channel. The design issues have to do with making sure that when one side sends a 1 bit, it is received by the other side as a 1 bit, not as a 0 bit. Typical questions here are how many volts should be used to represent a 1 and how many for a 0, how many microseconds a bit lasts, whether transmission may proceed simultaneously in both directions, how the initial connection is established, how it is torn down when both sides are finished, how many pins the network connector has, and what each pin is used for. The design issues here deal largely with mechanical, electrical, and procedural interfaces and the physical transmission medium, which lies below the Physical layer. Physical layer design can properly be considered to be within the electrical engineer's domain.

2. The Data Link layer

The Data Link layer describes the logical organization of data bits transmitted on a particular medium. This layer defines the framing, addressing, and check-summing of Ethernet packets. The main task of the Data Link layer is to transform a raw transmission facility into a line that appears free of transmission errors in the Network layer. It accomplishes this task by having the sender break the input data up into data frames (typically, a few hundred bytes), transmit the frames sequentially, and process the acknowledgment frames sent back by the receiver. Since the Physical layer merely accepts and transmits a stream of bits without any regard to meaning of structure, it is up to the Data Link layer to create and recognize frame boundaries. This can be accomplished by attaching special bit patterns to the beginning and end of the frame. If there is a chance that these bit patterns might occur in the data, special care must be taken to avoid confusion. The Data Link layer should provide error control between adjacent nodes.

Another issue that arises in the Data Link layer (and most of the higher layers as well) is how to keep a fast transmitter from "drowning" a slow receiver in data. Some traffic regulation mechanism must be employed in order to let the transmitter know how much buffer space the receiver has at the moment. Frequently, flow regulation and error handling are integrated, for convenience.

If the line can be used to transmit data in both directions, this introduces a new complication for the Data Link layer software. The problem is that the acknowledgment frames for A to B traffic compete for use of the line with data frames for the B to A traffic. A clever solution in the form of piggybacking has been devised.

3. The Network layer

The Network layer describes how a series of exchanges over various data links can deliver data between any two nodes in a network. This layer defines the addressing and routing structure of the Internet. The Network layer is concerned with controlling the operation of the subnet. A key design issue is determining how packets are routed from source to destination. Routes could be based on static tables that are "wired into" the network and rarely changed. They could also be determined at the start of each conversation, for example, a terminal session. Finally, they could be highly dynamic, being newly determined for each packet, to reflect the current network load.

If too many packets are present in the subnet at the same time, they will get in each other's way, forming bottlenecks. The control of such congestion also belongs to the Network layer.

Since the operators of the subnet may well expect remuneration for their efforts, often some accounting function is built into the Network layer. At the very least, the software must count how many packets or characters or bits are sent by each customer, to produce billing information. When a packet crosses a national border, with different rates on each side, the accounting can become complicated.

When a packet has to travel from one network to another to get to its destination, many problems can arise. The addressing used by the second network may be different from that of the first one; the second one may not accept the packet at all because it is too large; the protocols may differ; and so on. It is up to the Network layer to overcome all these problems to allow the interconnecting of the heterogeneous networks.

In broadcast networks, the routing problem is simple, so the network layer is often thin or even nonexistent.

4. The Transport layer

The Transport layer describes the quality and nature of the data delivery. This layer defines if and how retransmissions will be used to ensure data delivery. The basic function of the Transport layer is to accept data from the session layer, split it up into smaller units if need be, pass these to the Network layer, and ensure that all the pieces arrive correctly at the other end. Furthermore, all this must be done efficiently and in a way that isolates the Session layer from the inevitable changes in the hardware technology.

Under normal conditions, the Transport layer creates a distinct network connection for each transport connection required by the Session layer. If the transport connection requires a high throughput, however, the Transport layer might create multiple network connections, dividing the data among the network connections to improve throughput. On the other hand, if creating or maintaining a network connection is expensive, the Transport layer might multiplex several transport connections onto the same network connection to reduce the cost. In all cases, the Transport layer is required to make the multiplexing transparent to the Session layer.

The transport layer also determines what type of service to provide to the Session layer, and ultimately, the users of the network. The most popular type of transport connection is an error-free point-to-point channel that delivers messages in the order in which they were sent. However, other possible kinds of transport, service and transport isolated messages exist, with no guarantee about the order of delivery to multiple destinations. The type of service is determined when the connection is established.

The Transport layer is a true source-to-destination or end-to-end layer. In other words, a program on the source machine carries on a conversation with a similar program on the destination machine, using the message headers and control messages.

Many hosts are multiprogrammed, which implies that multiple connections will be entering and leaving each host. There needs to be some way to tell which message belongs to which connection. The transport header is one place where this information could be added.

In addition to multiplexing several message streams onto one channel, the Transport layer must establish and delete connections across the network. This requires some kind of naming mechanism, so that the process on one machine has a way of describing with whom it wishes to converse. There must also be a mechanism to regulate the flow of information, so that a fast host cannot overrun a slow one. Flow control between hosts is distinct from flow control between switches, although similar principles apply to both.

5. The Session layer

The Session layer describes the organization of data sequences larger than the packets handled by lower layers. This layer describes how request and reply packets are paired in a remote procedure call. The Session layer allows users on different machines to establish sessions between them. A session allows ordinary data transport, as does the transport layer, but it also provides some enhanced services useful in some applications. A session might be used to allow a user to log into a remote time-sharing system or to transfer a file between two machines.

One service provided by the Session layer is to manage dialogue control. Sessions can allow traffic to go in both directions at the same time, or in only one direction at a time. If traffic can only go one way at a time, the Session layer can help keep track of whose turn it is.

A related Session service is token management. For some protocols, it is essential that both sides do not attempt the same operation at the same time. To manage these activities, the Session layer provides tokens that can be exchanged. Only the side holding the token may perform the critical operation.

Another Session service is synchronization. Consider the problems that might occur when trying to complete a two-hour file transfer between two machines on a network with a 1 hour mean time between crashes. After each transfer is aborted, the whole transfer will have to start over again, and will probably fail again with the next network crash. To eliminate this problem, the Session layer provides a way to insert checkpoints into the data stream, so that after a crash, only the data after the last checkpoint has to be repeated.

6. The Presentation layer

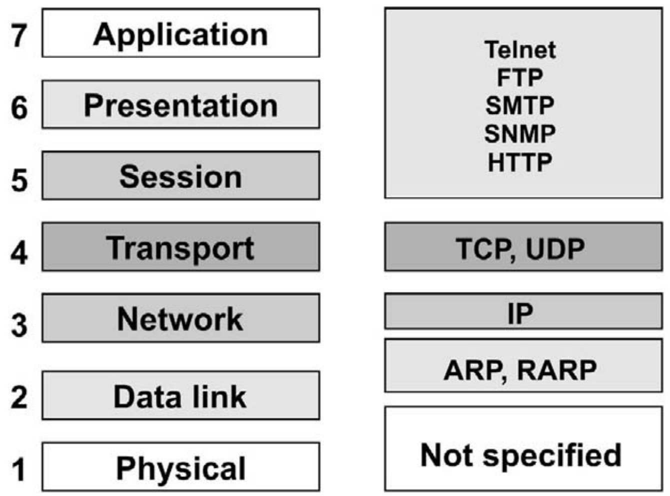
The Presentation layer describes the syntax of data being transferred. This layer describes how floating point numbers can be exchanged between hosts with different math formats. The Presentation layer performs certain functions that are requested sufficiently often to warrant finding a general solution for them, rather than letting each user solve the problems. In particular, unlike all the lower layers, which are just interested in moving bits reliably from here to there, the Presentation layer is concerned with the syntax and semantics of the information transmitted.

A typical example of a Presentation service is encoding data in a standard, agreed-upon way. Most user programs do not exchange random binary bit strings; they exchange things such as people's names, dates, amounts of money, and invoices. These items are represented as character strings, integers, floating point numbers, and data structures composed of several simpler items. Different computers have different codes for representing character strings, integers, and so on. In order to make it possible for computers with different representation to communicate, the data structures to be exchanged can be defined in an abstract way, along with a standard encoding to be used "on the wire." The Presentation layer handles the job of managing these abstract data structures and converting from the representation used inside the computer to the network standard representation.

The Presentation layer is also concerned with other aspects of information representation. For example, data compression can be used here to reduce the number of bits that have to be transmitted, and cryptography is frequently required for privacy and authentication.

7. The Application layer

The Application layer describes how real work actually gets done. This layer would implement file system operations. The Application layer contains a variety of protocols that are commonly needed. For example, there are hundreds of incompatible terminal types in the world. Consider the plight of a full-screen editor that is supposed to work over a network with many different terminal types, each with different screen layouts, escape sequences for inserting and deleting text, moving the cursor, and so on.



The OSI seven layers of networking and the relationship with the Internet protocols

One way to solve this problem is to define an abstract network virtual terminal for which editors and other programs can be written to. To handle each terminal type,

a piece of software must be written to map the functions of the network virtual terminal onto the real terminal. For example, when the editor moves the virtual terminal's cursor to the upper left-hand corner of the screen, this software must issue the proper command sequence to the real terminal to get its cursor there too. All the virtual terminal software is in the Application layer.

Another Application layer function is file transfer. Different file systems have different file naming conventions, different ways of representing text lines, and so on. Transferring a file between two different systems requires handling these and other incompatibilities. This work, too, belongs to the Application layer, as do electronic mail, remote job entry, directory lookup, and various other general-purpose and special-purpose facilities.

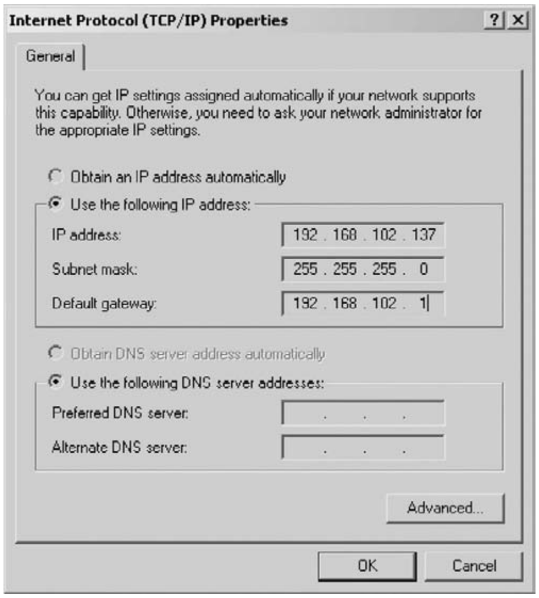
IP addresses

The ***Internet Protocol*** (IP) was created in the 1970s to support early computer networking with the Unix operating system. Today, IP has become a standard for all modern network operating systems to communicate with each other. Many popular, higher-level protocols such as HTTP and TCP rely on IP.

The Internet Protocol (IP) address uniquely identifies the node or Ethernet device, just as a name identifies a particular person.

No two Ethernet devices on the same network should ever have the same address.

Two versions of IP exist in production use today. **Nearly all networks use IP version 4 (IPv4)**, but an increasing number of educational and research networks have adopted the **next generation IP version 6 (IPv6)**.



Typical IP address setting in Microsoft Windows 2000

Since a signal on the Ethernet medium reaches every attached node, the destination address is critical to identify the intended recipient of the frame. For example, when computer B transmits to printer C, computers A and D will still receive and examine the frame. However, when a station first receives a frame, it checks the destination address to see if the frame is intended for itself. If it is not, the station discards the frame without even examining its contents.

One interesting aspect of Ethernet addressing is the implementation of a **broadcast address**. A frame with a destination address equal to the broadcast address (simply called a broadcast, for short) is intended for **every node** on the network, and every node will both receive and process.

Understanding the IP addressing is especially important

for the CCTV technical guys who visit various sites that have their own networks. In order to connect, program a DVR, or evaluate the network, one should not only have approval from the appropriate IT personnel at such a company, but should clearly understand how to set up their own PC to become part of the customer's network, without intruding or affecting it. Although it is possible, and perhaps much easier and safer, to connect to a DVR directly by using a crossover Cat-5 cable (that is, if you are physically close to it), it is still important to know how such an IP address can be accessed from one's own PC (not a part of the network one is visiting).

The few "classic" network ping-commands mentioned at the end of this chapter may help establish the validity of certain addresses.

IPv4 addressing notation

The most common IP address type is the IPv4, which consists of 4 bytes (32 bits).

These bytes are also known as octets.

For purposes of readability, humans typically work with IP addresses in a decimal notation that uses periods to separate each octet. For example, the IP address

11000000 10101000 1100110 1011010

shown in the binary system has the first 8 bits (octet) equivalent to the decimal representation of:

$$1\times2^7 + 1\times2^6 + 0\times2^5 + 0\times2^4 + 0\times2^3 + 0\times2^2 + 0\times2^1 + 0\times2^0 = 128 + 64 + 0 + 0 + 0 + 0 + 0 + 0 = 192$$

Similar logic applies to the other three octets, so that the decimal equivalent representation of the previous binary IP address is:

192.168.102.90

Because each byte is 8 bits in length, each octet in an IP address ranges in value from a minimum of 0 to a maximum of 255 (2^8).

Therefore, the full range of IP addresses in IPv4 annotation is from 0.0.0.0 through 255.255.255.255.

This represents a total of $256\times256\times256\times256 = 256^4$ = 4,294,967,296 possible IP addresses.

One could say that there are enough IP addresses for almost every single person on our planet, but do not forget that in the beginning of the twenty-first century our planet already has over 6 billion people. The growth of the Internet has been so rapid that larger addressing space is seen as inevitable introduction.

IP address classes

Not all IP addresses are free for use in your local LAN, which you will no doubt find from your IT manager. In addition, not all addresses that you could use can be used, for you have to find out what address is free to use and yet belongs to the same address group addressable by your network equipment.

In order to bring some order to the many possible LANs and WANs, there are some agreed-upon rules and address classes that all Ethernet devices obey. These are the IPv4 classes.

The IPv4 address space can be subdivided into five classes: Class A, B, C, D, and E.

Each class consists of a contiguous subset of the overall IPv4 address range.

With a few special exceptions explained later in this chapter, the values of the leftmost 4 bits of an IPv4 address determine its class as shown in this table.

Class	Leftmost bits	Start address	Finish address	
A	0xxx	0.0.0.0	127.255.255.255	OK to use (Private range 10.0.0.0 to 10.255.255.255)
B	10xx	128.0.0.0	191.255.255.255	OK to use - (Private range 172.16.0.0 to 172.31.255.255)
C	110x	192.0.0.0	223.255.255.255	OK to use - (Private range 192.168.0.0 to 192.168.255.255)
D	1110	224.0.0.0	239.255.255.255	Reserved for Multicasting
E	1111	240.0.0.0	255.255.255.255	Reserved for research

Class A, B, and C

Class A, B, and C are the three classes of addresses used on the Internet, with private addresses exceptions as explained next.

Private addresses

When a computer or a network device resides on a private network (not on the Internet), it should use one of the many private addresses defined by the IP standards. Such devices, when connected to the Internet, via an ADSL modem, for example, are practically invisible to the other Internet devices which use the other ("visible") Class A, B, or C IP addresses.

The IP standard defines specific address ranges within Class A, Class B, and Class C reserved for use by private networks (***intranets***). The following table lists these reserved ranges of the IP address space.

Nodes are effectively free to use addresses in the private ranges if they are not connected to the Internet, or if they reside behind firewalls or other gateways that use Network Address Translation (NAT).

Class	Private start address	Private finish address
A	10.0.0.0	10.255.255.255
B	172.16.0.0	172.31.255.255
C	192.168.0.0	192.168.255.255

Private address allocation in Class A, B, and C

IP address Class C

All Class C addresses, for example, have the leftmost 3 bits set to "110," but each of the remaining 29 bits may be set to either "0" or "1" independently (as represented by an x in these bit positions):

110xxxxx xxxxxxxx xxxxxxxx xxxxxxxx

By converting the above to dotted decimal notation, it follows that all Class C addresses fall in the range from 192.0.0.0 through 223.255.255.255.

IP loopback address

127.0.0.1 is the ***loopback address*** in IP.

Loopback is a test mechanism of network adaptors. Messages sent to 127.0.0.1 do not get delivered to the network. Instead, the adaptor intercepts all loopback messages and returns them to the sending application. IP applications often use this feature to test the behavior of their network interface. On some products this address is used to synchronize the time to a master device.

As with broadcast, IP officially reserves the entire range from 127.0.0.0 through 127.255.255.255 for loopback purposes. Nodes should not use this range on the Internet, and it should not be considered part of the normal Class A range.

Zero addresses

As with the loopback range, the address range from 0.0.0.0 through 0.255.255.255 should not be considered part of the normal Class A range.

0.x.x.x addresses serve no particular function in IP, but nodes attempting to use them will be unable to communicate properly on the Internet.

IP address Class D and Multicast

The IPv4 networking standard defines Class D addresses as reserved for multicast.

Multicast is a mechanism for defining groups of nodes and sending IP messages to that group rather than to every node on the LAN (broadcast) or just one other node (unicast).

Multicast is used mainly on research networks, but in some CCTV systems multicasting is a required feature. In a large digital matrix switcher where there are more than one user, multicasting can be used for sending the same packets of data (in our case video images) to various operators. This consequently reduces the data traffic as the same packets are received by multiple operators, rather than being transmitted separately.

As with Class E, Class D addresses should not be used by ordinary nodes on the Internet.

IP address Class E and limited broadcast

The IPv4 networking standard defines Class E addresses as reserved, which means that they should not be used on IP networks.

Some research organizations use Class E addresses for experimental purposes. However, nodes that try to use these addresses on the Internet will be unable to communicate properly.

A special type of IP address is the limited broadcast address 255.255.255.255. A broadcast involves delivering a message from one sender to many recipients. Senders direct an IP broadcast to 255.255.255.255 to indicate that all other nodes on the local network (LAN) should pick up that message. This broadcast is "limited" in that it does not reach every node on the Internet, only nodes on the LAN.

Technically, IP reserves the entire range of addresses from 255.0.0.0 through 255.255.255.255 for broadcast, and this range should not be considered part of the normal Class E range.

IP network partitioning

Computer networks consist of individual segments of network cable. The electrical properties of cabling limit the useful size of any given segment such that even a modestly sized local area network (LAN) will require several of them. Gateway devices such as routers and bridges connect these segments together, though not in a perfectly seamless way.

Besides partitioning through the use of cable, subdividing of the network can also be done at a higher level. Subnets support virtual network segments that partition traffic flowing through the cable rather than the cables themselves. The subnet configuration often matches the segment layout one to one, but subnets can also subdivide a given network segment.

Network addressing fundamentally organizes hosts into groups. This can improve security (by isolating critical nodes) and can reduce network traffic (by preventing transmissions between nodes that do not need to communicate with each other). Overall, **network addressing becomes even more powerful when introducing subnetting and/or supernetting.**

Virtual private networking (VPN)

A VPN utilizes public networks to conduct private data communications. Most VPN implementations use the Internet as the public infrastructure and a variety of specialized protocols to support private communications through the Internet. VPN follows a client and server approach. VPN clients authenticate users, encrypt data, and otherwise manage sessions, with VPN servers utilizing a technique called tunneling.

Subnetting

The governing bodies that administer Internet Protocol have reserved certain networks for internal uses. In general, intranets utilizing these networks gain more control over managing their IP configuration and Internet access. A subnet allows the flow of network traffic between hosts to be segregated based on a network configuration. By organizing hosts into logical groups, subnetting can improve network security and performance. Subnetting works by applying the concept of extended network addresses to individual computer (and other network device) addresses.

An extended network address includes both a network address and additional bits that represent the subnet number. Together, these two data elements support a two-level addressing scheme recognized by standard implementations of IP. The network address and subnet number, when combined with the host address, therefore support a three-level scheme.

IPv6 addressing notation

Although this addressing is not widespread as yet, it is no doubt something that future networks will have use of, if nothing else because of the amount of addresses made available under such notation. The IPv6 addresses are 16 bytes (128 bits) long, rather than 4 bytes (32 bits).

This represents more than

300,000,000,000,000,000,000,000,000,000,000,000,000

possible addresses (256^{16}).

The preferred IPv6 addressing form is using hexadecimal values of the eight 16-bit pieces:

BA98:FEDC:800:7654:0:FEDC:BA98:7654:3210

In hexadecimal representation of numbers, rather than decimal, the numbers use A as 11 in decimal, B is 12, C is 13, D is 14, E is 15, and F is 16.

Note that it is not necessary to write the leading zeros in an individual field, but there must be at least one numeral in every field.

In the coming years, as an increasing number of cell phones, PDAs, and other network appliances

expand their networking capability, this much larger IPv6 address space will probably be necessary.

IPv6 Address Types

IPv6 does not use classes. IPv6 supports the following three IP address types:

- Unicast
- Multicast
- Anycast

Unicast and multicast messaging in IPv6 are conceptually the same as in IPv4.

IPv6 does not support broadcast, but its multicast mechanism accomplishes essentially the same effect. Multicast addresses in IPv6 start with "FF" (255) just like IPv4 addresses.

Anycast in IPv6 is a variation on multicast. Whereas multicast delivers messages to all nodes in the multicast group, anycast delivers messages to any one node in the multicast group. Anycast is an advanced networking concept designed to support the fail over and load balancing needs of applications.

Reserved addresses in IPv6

IPv6 reserves just two special addresses: 0:0:0:0:0:0:0:0 and 0:0:0:0:0:0:0:1.

IPv6 uses 0:0:0:0:0:0:0:0 internal to the protocol implementation, so nodes cannot use it for their own communication purposes.

IPv6 uses 0:0:0:0:0:0:0:1 as its loopback address, equivalent to 127.0.0.1 in IPv4.

Domain Name Systems (DNS)

Although IP addresses allow computers and routers to identify each other efficiently, humans prefer to work with names rather than numbers.

The ***Domain Name System*** (DNS) supports the best of both worlds.

DNS allows nodes on the public Internet to be assigned both an IP address and a corresponding name called a domain name. For DNS to work as designed, these names must be unique worldwide. Hence, an entire "cottage industry" has emerged around the purchasing of domain names in the Internet name space.

DNS is a hierarchical system and organizes all registered names in a tree structure.

At the base or root of the tree are a group of top-level domains including familiar names like ***com***, ***org***, and ***edu*** and numerous country-level domains like ***au*** (Australia), ***fi*** (Finland), or ***uk*** (United Kingdom).

One generally cannot purchase names at this level. However, in a well-publicized and controversial event in 2000, the island nation of Tuvalu agreed to receive a large payment in return for rights to the root domain ***tv***.

Below this level are the second-level registered domains such as ***cctvlabs.com***. These are domains that organizations can purchase from any of numerous accredited registrars.

For nodes in the ***com***, ***org***, and ***edu*** domains, the Internet Corporation for Assigned Names and Numbers (ICANN) oversees registrations. Below that, local domains like ***cctvfocus.cctvlabs.com*** are defined and administered by the overall domain owner. DNS supports additional tree levels as well.

The period (the dot '.') always separates each level of the hierarchy in DNS.

DNS is also a distributed system. The DNS database contains a list of registered domain names. It further contains a mapping or conversion between each name and one or more IP addresses. However, DNS requires a coordinated effort among many computers (servers); **no one computer holds the entire DNS database**. Each DNS server maintains just one piece of the overall hierarchy – one level of the tree and then only a subset or zone within that level.

The top level of the DNS hierarchy, also called the root level, is maintained by a set of 13 servers called root name servers. These servers have gained some notoriety for their unique role on the Internet. Maintained by various independent agencies, the servers are uniquely named A, B, C, and so on up to M. Ten of these servers reside in the United States, one in Japan, one in London, and one in Stockholm, Sweden.

DNS works in a client/server fashion. The DNS servers respond to requests from DNS clients called resolvers. ISPs and other organizations set up local DNS resolvers as well as servers. Most DNS servers also act as resolvers, routing requests up the tree to higher-level DNS servers and delegating requests to other servers. DNS servers eventually return the requested mapping (either address-to-name or name-to-address) to the resolver.

DHCP

DHCP (***Dynamic Host Configuration Protocol***) is a protocol that lets network administrators centrally manage and automate the assignment of IP addresses on the corporate network. When a company sets up its computer users with a connection to the Internet, an IP address must be assigned to each machine. Without DHCP, the IP address must be entered manually at each computer on the corporate network.

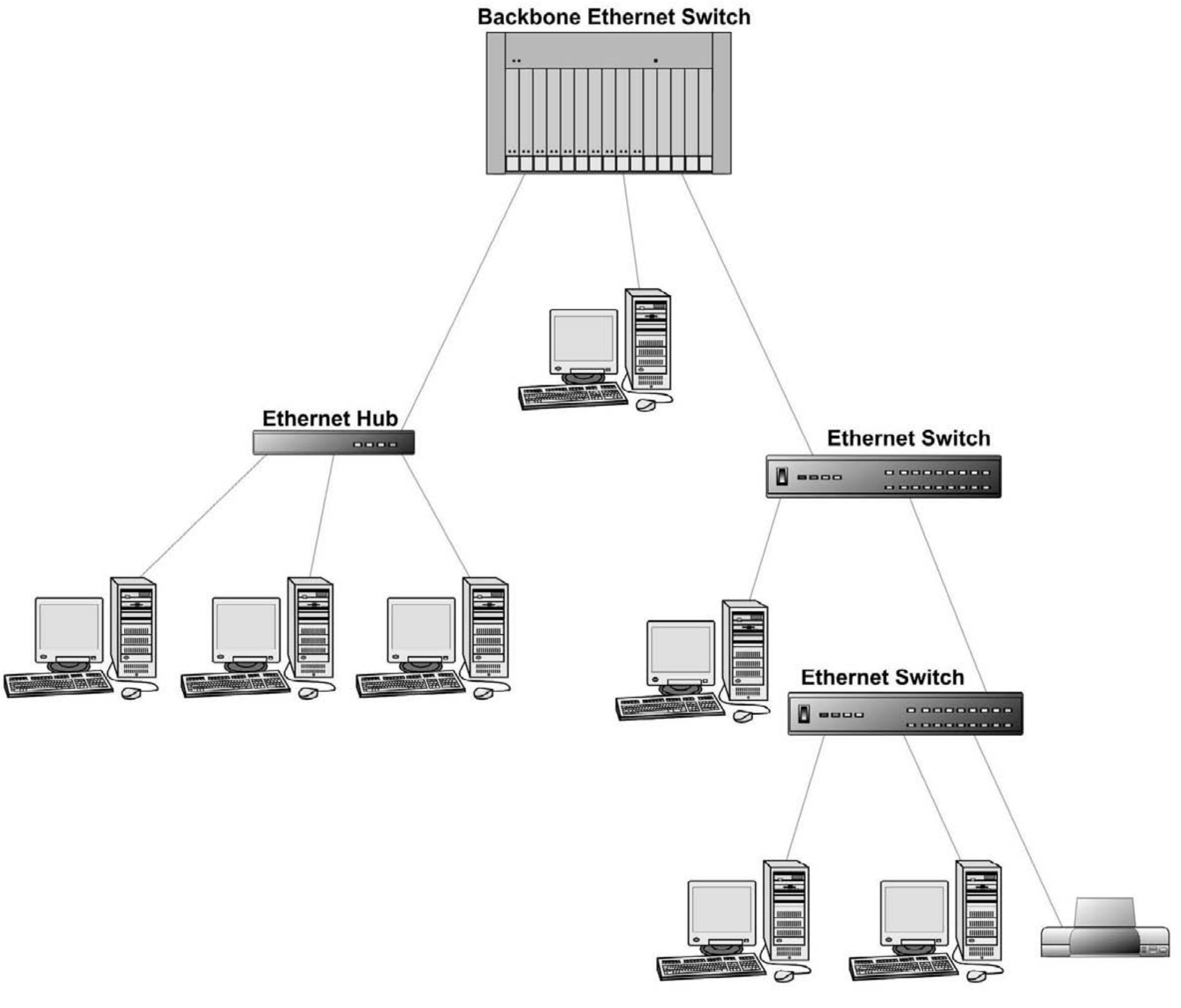
DHCP permits a network administrator to supervise and distribute IP addresses from a central point and automatically sends a new IP address when a computer is plugged into a different place in the network. DHCP uses the concept of a "lease" or amount of time that a given IP address will be valid

for a computer. Using very short leases, DHCP can dynamically reconfigure networks in which there are more computers than there are available IP addresses.

DNS and DHCP

DNS was not designed to work with dynamic addressing such as that supported by DHCP. It requires that fixed (static) addresses be maintained in the database. Web servers in particular require fixed IP addresses for this reason.

Many CCTV systems that are designed to be accessible from remote locations via Internet need to have fixed public IP address instead of a domain name. Such fixed addresses are available from most Internet Service Providers (ISP) at an additional cost.



A LARGER ETHERNET NETWORK

Networking hardware

Hubs, bridges, and switches

Hubs classify as Layer 1 devices in the OSI model. Hubs connect multiple Ethernet devices in a star configuration, so that any device connected to the hub can "see" and talk to any other device in that group (network segment).

At the Physical layer, hubs can support little in the way of sophisticated networking. **Hubs do not read any of the data passing through them and are not aware of their source or destination.** Essentially, a hub simply receives incoming packets, possibly amplifies the electrical signal, and broadcasts these packets out to all devices on the network, including the one that originally sent the packet. Typically, 4, 8, 16, or up to 24 devices can be connected to one hub since there are no hubs with more than 24 ports. If more devices are used, more hubs can be added.

Because Ethernet works on the principle of carrier-sense multiple access with collision detection (**CSMA/CD**) it is quite obvious that the more devices are connected to the hub the **more data packets collision will occur, slowing down the network traffic**. One way to reduce data congestion would be to split a single segment into multiple segments, thus creating **multiple collision domains**. This solution creates a different problem, for these now separate segments are not able to share information with each other. This is where network bridges and switches are used.



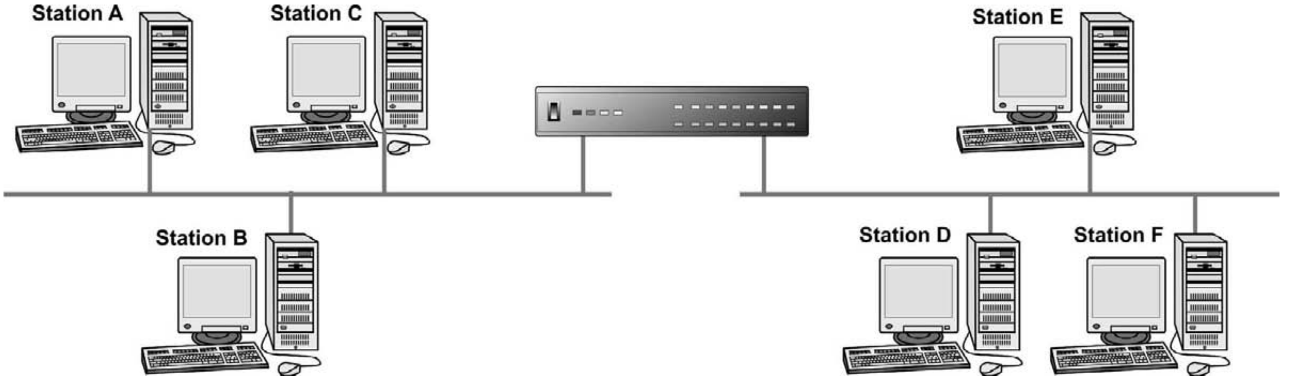
Photo courtesy of Micronet

Various size hubs

Bridges and switches are data communications devices that operate principally at Layer 2 of the OSI reference model. Bridging and switching occur at the Data Link layer, which controls data flow, handles transmission errors, provides physical (as opposed to logical) addressing, and manages access to the physical medium. Bridges provide these functions by using various link layer protocols that dictate specific flow control, error handling, addressing, and media-access algorithms. Bridges and switches are not complicated devices. **They analyze incoming frames, make forwarding decisions based on information contained in the frames**, and forward the frames toward the destination. In some cases, such as source-route bridging, the entire path to the destination is contained in each frame. In other cases, such as transparent bridging, frames are forwarded one hop at a time toward the destination.

Bridges became commercially available in the early 1980s. Like bridges in our daily lives that connect one side of a river with another, network bridges connect one group of Ethernet devices with another. At the time of their introduction, bridges connected and enabled packet forwarding between homogeneous networks, but more recently, bridging between different networks has also been defined and standardized. Several kinds of bridging have proven important as internetworking devices so that transparent

bridging is found primarily in Ethernet environments, while source-route bridging occurs primarily in Token Ring environments. Translational bridging provides translation between the formats and transit principles of different media types, such as Ethernet and Token Ring.



Network bridge

Bridges connect two or more network segments, increasing the network diameter (as a repeater does), but they also help **regulate traffic**. They send and receive transmissions just like any other node, but they do not function in the same way as a normal node. **The bridge does not originate any traffic of its own, it only echoes what it hears from other stations**. So, one goal of the bridge is to **reduce unnecessary traffic** on both segments. This is done by examining the destination address of the frame before deciding how to handle it. If the destination address, for example, is that of station A or B (see the illustration), then there is no need for the frame to appear on a segment where A and B are not members. In this case, the bridge does nothing. We can say that the bridge filters or drops the frame. If the destination address is that of station C or D, or if it is the broadcast address, then the bridge will transmit or forward the frame onto the segments where C and D are. By forwarding packets, the bridge allows any of the devices of different segments to communicate. In addition, by filtering packets when appropriate, the bridge makes it possible for station A to transmit to station B at the same time that station C transmits to station D, allowing two conversations to occur simultaneously.



Photo courtesy of Linksys

24-port gigabit switch

Switches are the modern counterparts of bridges, functionally equivalent but offering a **dedicated segment** for every node on the network. **Switches are Data Link layer devices that, like bridges, enable multiple physical LAN segments to be interconnected into a single larger network.**

LAN switches are used to interconnect multiple LAN

segments. LAN switching provides dedicated, collision-free communication between network devices, with support for multiple simultaneous conversations. LAN switches are designed to switch data frames at high speeds.

By dividing large networks into self-contained units (segments), bridges and switches provide several advantages:

- Because only a certain percentage of traffic is forwarded, **a bridge or switch reduces the unnecessary traffic and the network becomes more efficient.**

- **The bridge or switch will act as a firewall** for some potentially damaging network errors and will accommodate communication between a larger number of devices than would be supported on any single LAN connected to the bridge.

- **Bridges and switches extend the effective length of a LAN**, permitting the attachment of distant stations that was not previously permitted.

Although bridges and switches share most relevant attributes, several distinctions differentiate these technologies. **Bridges are generally used to segment a LAN into a couple of smaller segments, whereas switches are generally used to segment a large LAN into many smaller segments. Bridges generally have only a few ports for LAN connectivity, and switches generally have many.**

Switches can also be used to connect LANs with different media – for example, a 10 Mb/s Ethernet LAN and a 100 Mb/s Ethernet LAN can be connected using a switch. Some switches support cut-through switching, which reduces latency and delays in the network, whereas bridges support only store-and-forward traffic switching. Finally, switches reduce collisions on network segments because they provide dedicated bandwidth to each network segment.

Modern Ethernet implementations often look nothing like their historical counterparts. Where long runs of coaxial cable provided attachments for multiple stations in legacy Ethernet, modern Ethernet networks use twisted pair wiring or fiber optics to connect stations in a ***radial pattern*** **(*star-configuration*)**. Where legacy Ethernet networks transmitted data at 10 Mb/s, modern networks can operate at 100, 1000 Mb/s, or even 10,000 Mb/s.

Ethernet switching gave rise to another advancement: full-duplex Ethernet. ***Full-duplex*** is a data communications term that refers to the ability to send and receive data at the same time. Legacy Ethernet is half-duplex, meaning information can move in only one direction at a time. In a totally switched network, nodes only communicate with the switch and never directly with each other. Switched networks also employ either twisted pair or fibre optic cabling, both of which use separate conductors for sending and receiving data. In this type of environment, Ethernet stations can forgo the collision detection process and transmit at will, since they are the only potential devices that can access the medium. This allows end stations to transmit to the switch at the same time that the switch transmits to them, achieving a ***collision-free*** environment.



Routers for logical segmentation

Bridges and switches can reduce congestion by allowing multiple conversations to occur on different segments simultaneously, but they have their limits in segmenting traffic as well.

An important characteristic of bridges is that they forward Ethernet broadcasts to all connected segments. This behavior is necessary, as Ethernet broadcasts are destined for every node on the network, but it can pose problems for bridged networks that grow too large. When a large number of stations broadcast on a bridged network, congestion can be as bad as if all those devices were on a single segment.

Routers are "intelligent" networking components that can divide a single network into two logically separate networks. While Ethernet broadcasts cross bridges in their search to find every node on the network, they do not cross routers, because **the router forms a logical boundary for the network**.

Routers operate based on protocols that are independent of the specific networking technology, such as Ethernet or token ring. **This allows routers to easily interconnect various network technologies**, both local and wide area, and has led to their widespread deployment in connecting devices around the world as part of the global Internet.

Network ports

A ***network port*** is an interface for communicating with a computer program over a network. Network ports are usually numbered, and a network implementation (like TCP or UDP) will attach a port number to data it sends. The receiving implementation will use the attached port number to figure out which computer program to send the data to. The combination of a port and a network address (IP-number) is often called a ***socket***.

There are a total of 65,536 ports used on a networking device, which comes from the 16 bits allocated to addressing the port numbers (2^{16}).

Not all ports of a network device are known , but there is a general division into three groups:

- The ***Well-Known Ports*** are those from 0 through 1023.
- The ***Registered Ports*** are those from 1024 through 49151.
- The ***Dynamic*** and/or ***Private Ports*** are those from 49152 through 65535.

For example, some of the Well-Known Ports are:

- 20 – FTP: the file transfer protocol – data
- 21 – FTP: the file transfer protocol – control
- 22 – SSH: secure logins, file transfers (scp, sftp), and port forwarding

- 23 – Telnet: nonsecure text communications
- 25 – SMTP: Simple Mail Transfer Protocol (E-mail)
- 53 – DNS: Domain Name Server
- 80 – HTTP: HyperText Transfer Protocol (www)
- 110 – POP3: Post Office Protocol (E-mail)
- 143 – IMAP4: Internet Message Access Protocol (E-mail)
- 443 – HTTPS: used for securely transferring web pages, etc.

Ports can be closed, depending on the requirement and in order to minimize any risk from external hacker attacks. In some tightly controlled network environments, certain ports need to be opened in order to have a certain function of a DVR system, for example, accessible from a remote location. This is usually negotiated with the appropriate IT manager of the company using such a system.

A network analogy example

In order to summarize all the aforementioned network concepts and devices, which for many in CCTV might be a bit daunting, let me share with you the following analogy:

Imagine you live in a nice little town. The town could represent your Wide Area Network (WAN), while your own suburb would represent the Local Area Network (LAN) segment. Each house, shop, or object would represent a network device, with its own address, which is basically the IP address in a network. All the houses in your own street have different numbers but carry the name of the street, which is exactly how it is in the Local Area Network, where all devices have the first three groups of IP numbers the same and the last is unique to each house. No two houses in the same street have the same number. If one of the houses is better known by its owner's name or the business name residing on that address, that will be equivalent to DNS address allocation instead of the IP number (in our analogy, the house number).

Imagine now that you have a variety of roads in your town, with many vehicles traveling in various directions. In our networking analogy each road would represent the Ethernet media (cable), and each vehicle driving on that road would represent a data packet. The roads are narrow and have traffic flowing in both directions, so that you cannot go any quicker than what the vehicle's speed is in front of you, and you can only use one-half of the road width, which is equivalent to half-duplex data in network communications. If intersections are not regulated with traffic lights, you basically have the equivalent of hub devices in networking. They do not regulate the traffic intelligently; they only allow you to get from one street to another, but if you have many cars going in various directions, the waiting time in front of such intersections could be quite long. This is equivalent to the data packets collision in Ethernet terminology.

On your way to the chemist shop, you might drive on a brand-new four-lane-wide road (equivalent to 100 Mb/s network), which will get you there quite quickly because there are not that many accidents or stops (data collisions) and because the road is pretty wide and divided (equivalent to full-duplex Ethernet). When you get to the traffic lights before you cross over to the other side where the shopping center might be, it is like getting to a network bridge that separates your traffic from the shopping center traffic. If this were a major traffic intersection with five roads joining, for example, where some roads can take you to other parts of your town, such as the industrial, the traffic intersection and its intelligent traffic light switching would be equivalent to a network switch.

As it happens in real life, each vehicle could have a different size, which is similar to what we have in Ethernet data packets. They could all have a different length and different sizes, and of course different content, which is like having a different number of passengers or items being transported in a vehicle.

In order for a vehicle to get from its original location (your home, for example) to the chemist shop which is near the shopping center (your destination, for example), your driver must know the address of the chemist shop, which is the same as having an IP address of the destination.

Let us now assume you want to go into the main shopping center, and let us also assume you have your friend with you, who unfortunately happens to be disabled and uses a wheelchair. In order for you to take him to the shopping center, you would take him via the wheelchair ramp that is designed for such purposes. The wheelchair ramp is another access to the shopping center, which nondisabled people usually do not use. The shopping center is the IP address you know and went to, but the access for your disabled friend is via the wheelchair ramp, for he cannot get up the stairs. This is exactly the same as having a different port on an Ethernet device, designed only for such purposes (i.e., customers). The shopping center delivery docks would be another way into the shopping center, but it is dedicated only to the trucks that deliver goods to the shopping center shops. Again, this is equivalent to another port number of the same IP address (i.e., the shopping center). In CCTV applications, for example, one DVR can have one port for accessing images, and another for accessing the time server function.

Pursuing this analogy, let us now assume that you want to leave your lovely town (your own network) and want to go outside, which happens to be another state, where you have border control, and they will not let you go there unless you have all the right vehicle documents and passport. This would be equivalent to a router device in a network, equipped with a firewall control.

Hackers or viruses are equivalent to either polite door-knocking salesmen (intruders), or robbers that want to come and steal something from your house and at the same time make a mess, or even burn it down.

The following heading, Wireless LAN, is equivalent in our analogy to having helicopters instead of cars, where you can get to any point (in a certain radius, of course, depending upon the helicopter power and fuel) flying in the air, without the need to build roads on the ground (copper or fiber Ethernet). The flight control tower will still have to keep the traffic in order, which is the equivalent of the wireless network bridge or hot-spot.

Wireless LAN

An increasing number of CCTV products and projects are starting to use wireless LAN (WLAN). The acceptance and practicality of wireless communications between computers, routers, or digital video devices is becoming so widespread that manufacturers are being forced to bring out even better and cheaper devices. After many years of proprietary products and ineffective standards, the industry has finally decided to back one set of standards for wireless networking: the 802.11 series from the Institute of Electrical and Electronics Engineers (IEEE). These emerging standards define wireless Ethernet, or wireless LAN (WLAN), also referred to as Wi-Fi (Wireless Fidelity).

There are, however, many "flavors" of the 802.11 standards, with more of them being issued, so it might be useful for the CCTV users to obtain a better understanding of which one is what (at least until the time of writing this book).



Photo courtesy of Linksys

Wireless network bridge

Sales are expanding rapidly as an increasing number of enterprises see the value of WLANs. Growth has been helped by the Wireless Ethernet Compatibility Alliance (WECA), which provides conformance and interoperability testing. So far, this group of more than 130 companies has granted its "Wi-Fi" label of approval to more than two hundred products conforming to the 802.11b standard.

Within the IEEE's 802.11 series there are several specifications, some complete and some still under development.

What is 802.11?

IEEE 802.11, or Wi-Fi, denotes a set of Wireless LAN standards developed by working group 11 of the IEEE 802 group. The term is also used specifically for the original version; to avoid confusion, that is sometimes called "802.11 legacy."

The 802.11 family currently includes three separate protocols that focus on encoding (a, b, g); security was originally included but is now part of other family standards (e.g., 802.11i). Other standards in the family (c-f, h-j, n) are service enhancement and extensions, or corrections to previous specifications.

802.11b was the first widely accepted wireless networking standard, followed, paradoxically, by 802.11a and 802.11g.

The frequencies used by the 802.11 are in the microwave range and most are subject to minimal governmental regulation. Licenses to use this portion of the radio spectrum are not required in most locations.

802.11 (legacy)

The original version of the standard IEEE 802.11 released in 1997 and sometimes called "802.1y" specifies two data rates of 1 and 2 megabits per second (Mb/s) to be transmitted via infrared (IR) signals or in the Industrial Scientific Medical frequency band at 2.4 GHz.

IR has been dropped from later revisions of the standard because it could not succeed against the well established IrDA protocol and has had no actual implementations. Legacy 802.11 was rapidly succeeded by 802.11b.

802.11b

802.11b has a range of about 50 meters, with the low-gain omnidirectional antennas typically used in 802.11b devices. 802.11b has a maximum throughput of 11 Mb/s; however, a significant percentage of this bandwidth is used for communications overhead. In practice, the maximum throughput is about 5.5 Mb/s. Metal, water, and thick walls absorb 802.11b signals and decrease the range drastically. 802.11 runs in the 2.4 GHz spectrum and uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) as its media access method.

With high-gain external antennas, the protocol can also be used in fixed point-to-point arrangements, typically at ranges up to 8 kilometers (although some report success at ranges up to 80 – 120 km where line of sight can be established). This is usually done to replace costly leased lines, or in place of very cumbersome microwave communications gear. Current cards can operate at 11 Mb/s but will scale back to 5.5 Mb/s, then 2 Mb/s, and then 1 Mb/s, if signal strength becomes an issue.

Extensions have been made to the 802.11b protocol (e.g., channel bonding and burst transmission techniques) in order to increase speed to 22 Mb/s, 33 Mb/s, and 44 Mb/s, but the extensions are proprietary and have not been endorsed by the IEEE.

Many companies call enhanced versions "802.11b+".

The first widespread commercial use of the 802.11b standard for networking was made by Apple Computer under the trademark AirPort.

802.11a

In 2001, 802.11a, a faster related protocol started shipping even though the standard was ratified in 1999. The 802.11a standard uses the 5 GHz band, and operates at a raw speed of 54 Mb/s and more realistic net achievable speeds in the mid-20 Mb/s. The speed is reduced to 48, 36, 34, 18, 12, 9, and

then 6 Mb/s if required. 802.11a has 12 nonoverlapping channels, 8 dedicated to indoor and 4 to point to point.

Different countries have different ideas about regulatory support, although a 2003 World Radiotelecommunications Conference made it easier for use worldwide.

802.11a has not seen wide adoption because of the high adoption rate of 802.11b and because of concerns about range: at 5 GHz, 802.11a cannot reach as far as 802.11b, other things (such as same power limitations) being equal. It is also absorbed more readily.

Most manufacturers of 802.11a equipment countered the lack of market success by releasing dual-band/dual-mode or tri-mode cards that can automatically handle 802.11a and b or a, b, and g as available. Access point equipment that can support all these standards simultaneously is also available.

802.11g

In June 2003, a third standard for encoding was ratified: 802.11g. This flavor works in the 2.4 GHz band (like 802.11b) but operates at 54 Mb/s raw, or about 24.7 Mb/s net, throughput like 802.11a. It is fully backwards compatible with b and uses the same frequencies. Details of making b and g work together well occupied much of the lingering technical process. However, the presence of an 802.11b participant reduces an 802.11g network to 802.11b speeds.

The 802.11g standard swept the consumer world of early adopters starting in January 2003, well before ratification. The corporate users held back and Cisco and other big equipment makers waited until ratification. By summer 2003, announcements were flourishing. Most of the dual-band 802.11a/b products became dual-band/tri-mode, supporting a, b, and g in a single card or access point.

A new feature called Super G is now integrated in certain access points. These can boost network speeds up to 108 Mb/s by using channel bonding. This feature may interfere with other networks and may not support all b and g client cards. In addition, packet bursting techniques are also available in some chipsets and products which will also considerably increase speeds. Again, they may not be compatible with some equipment.

The first major manufacturer to use 802.11g was Apple, under the trademark AirPort Extreme.



Photo courtesy of Linksys

Wireless network camera

802.11b and 802.11g divide the spectrum into 14 overlapping, staggered channels of 22 megahertz (MHz) each. Channels 1, 6,

11, and 14 have minimal overlap, and those channels (or other sets with similar gaps) can be used where multiple networks cause interference problems. Channels 10 and 11 are the only channels which work in all parts of the world, because Spain and France have not licensed channels 1 to 9 for 802.11b operation.

802.11n

In January 2004 IEEE announced that it will develop a new standard for wide area wireless networks. The real speed would be 100 Mb/s (even 250 Mb/s in the Physical level), and so up to 4–5 times faster than 802.11g and perhaps 50 times faster than 802.11b. As projected, 802.11n will also offer a better operating distance than current networks. The standardization progress is expected to be completed by the end of 2005, after the publishing date of this book, so stay tuned.

Certification and security

Because the IEEE only sets specifications but does not test equipment for compliance with them, a trade group called the Wi-Fi Alliance runs a certification program that members pay to participate in. Virtually all companies selling 802.11 equipment are members. The Wi-Fi trademark, owned by the group and usable only on compliant equipment, is intended to guarantee interoperability. The Wi-Fi label means compliant with any of 802.11a, b, or g. It also includes the security standard Wi-Fi Protected Access or WPA. Eventually Wi-Fi will also mean equipment that implements the 802.11i security standard (also known as WPA2). Products that are Wi-Fi are also supposed to indicate the frequency band in which they operate in 2.4 or 5 GHz.

With the proliferation of cable modems and DSL, there has arisen an ever-increasing market of people who wish to establish small networks in their homes to share their high-speed Internet connection.

Wired Equivalent Privacy (WEP) was an encryption algorithm designed to provide wireless security for users implementing 802.11 wireless networks. WEP was developed by a group of volunteer IEEE members. The intention was to offer security through an 802.11 wireless network while the wireless data was transmitted from one end point to another over radio waves. WEP was used to protect wireless communication from eavesdropping (confidentiality), prevent unauthorized access to a wireless network (access control), and prevent tampering with transmitted messages (data integrity). Wireless office networks are often unsecured or secured with WEP, which is easily broken. These networks frequently allow "people on the street" to connect to the Internet. Volunteer groups have also made efforts to establish wireless community networks to provide free wireless connectivity to the public.

The ***Wi-Fi Protected Access*** (WPA) is a standards-based interoperable security specification. The specification is designed so that only software or firmware upgrades are necessary for the existing or legacy hardware to meet the requirements. Its purpose is to increase the level of security for existing and future wireless LANs. WPA is an interim security solution that targets all known WEP vulnerabilities. It will be forward compatible with the new 802.11i standard, which will be the ultimate wireless security solution. All products are supposed to comply with the 802.11i standard once released.

What about Bluetooth?

If asked to construct a Wireless Local Area Network (WLAN), most IT managers would think of 802.11b wireless Ethernet technology. Few would consider using another short-range radio technology, ***Bluetooth***, on its own or in combination with 802.11b-based equipment.

The reason for its neglect is that Bluetooth has been marketed as a technology for linking devices such as phones, headsets, PCs, digital cameras, and other peripherals, rather than as a technology for LANs.

However, Bluetooth could become a serious WLAN option, partly because a lot more Bluetooth devices have been released lately. But IT managers may think twice before supporting this technology because 802.11b and Bluetooth use the same 2.4 GHz spectrum to transmit data, so interference is a real possibility.

Bluetooth is also closing the gap in signal range. Some companies are testing new ceramic antennas that will boost the range of Bluetooth to around 50 meters, up from the 10 meters currently specified and on a par with the maximum range offered by 802.11b components.

The wireless network standards summary

Standard	Transfer Method	Frequencies	Data Rates Supported (Mbit/s)
802.11 legacy	FHSS, DSSS, infrared	2.4 GHz, IR	1, 2
802.11b	DSSS, HR-DSSS	2.4 GHz	1, 2, 5.5, 11
"802.11b+" non-standard	DSSS, HR-DSSS (PBCC)	2.4 GHz	1, 2, 5.5, 11, 22, 33, 44
802.11a	OFDM	5.2, 5.5 GHz	6, 9, 12, 18, 24, 36, 48, 54
802.11g	DSSS, HR-DSSS, OFDM	2.4 GHz	1, 2, 5.5, 11; 6, 9, 12, 18, 24, 36, 48, 54

where: FHSS = Frequency Hopping Spread Spectrum
DSSS = Direct Sequence Spread Spectrum
HR-DSSS = High Rate Direct Sequence Spread Spectrum
OFDM = Orthogonal Frequency Division Multiplexing

The IEEE 802 network standards

802.11	Family of specifications for wireless local area network (WLAN) use Employs phase-shift keying Provides a wireless alternative to wired Ethernet LANs Several enhancements (variations) as defined below:
802.11a	Enhancement to 802.11 that applies to wireless ATM systems Used in access hubs Enhanced data speed Frequency range 5.725 GHz to 5.850 GHz
802.11b	Enhancement to 802.11 that employs complementary code keying (CCK) High data speed Low susceptibility to multipath-propagation interference Frequency range 2.400 GHz to 2.4835 GHz
802.11d	Enhancement to 802.11 that allows for global Roaming Attributes similar to 802.11b Particulars can be set at Media Access Control (MAC) layer
802.11e	Enhancement to 802.11 that includes Quality of Service (QoS) features Facilitates prioritization of data, voice, and video transmissions
802.11g	Enhancement to 802.11 that offers wireless transmission over relatively short distances Operates at up to 54 megabits per second (Mb/s)
802.11h	Enhancement to 802.11a that resolves interference issues Dynamic frequency selection (DFS) Transmit power control (TPC)
802.11i	Enhancement to 802.11 that offers additional security for WLAN applications
802.11j	Japanese regulatory extensions to 802.11a specification Frequency range 4.9 GHz to 5.0 GHz
802.11k	Radio resource measurements for networks using 802.11 family specifications
802.11m	Maintenance of 802.11 family specifications Corrections and amendments to existing documentation
802.11x	Generic term for 802.11 family specifications under development General term for all 802.11 family specifications
Wi-Fi	Originally created to ensure compatibility among 802.11b products Can run under any 802.11 standard Indicates interoperability certification by Wi-Fi Alliance
802.15	A communications specification for wireless personal area networks (WPANs)
802.16	A group of broadband wireless communications standards for metropolitan area networks (MANs)
802.16a	Enhancement to 802.16 for non-line-of-sight extensions in the 2-11 GHz spectrum Delivers up to 70 Mbps at distances up to 31 miles
802.16e	Enhancement to 802.16 that enables connections for mobile devices
802.1X	Designed to enhance the security of wireless local area networks (WLANs) that follow the IEEE 802.11 standard Provides an authentication framework for wireless LANs The algorithm that determines user authenticity is left open Multiple algorithms are possible
802.3	A standard specification for Ethernet Specifies the physical media and the working characteristics of the network
802.5	Standard specification for Token Ring networks

Putting a network system together

Although CCTV professionals cannot replace IT managers in various companies, it is important for them to be able to use the basic network ideas and principles in order to set up a digital camera or a DVR on the network.

As an example (shown on the next page) I have drawn a small CCTV hybrid system, with two operators, 3 DVRs, a number of analog cameras connected to the DVRs, and two network cameras in the system.

The system is hybrid: the analog cameras are connected to the DVRs, while the network IP cameras are connected to the network switch. So we have a digital recording system, but are still using analog cameras, as is done typically in most of the new CCTV systems today. In addition, a network printer is attached as well as a network area storage (NAS) device on the same network switch.

This configuration can allow for any recorded footage to be stored on the NAS for indefinite time, while the DVRs are usually recording in loop mode, that is, using the first in first out concept.

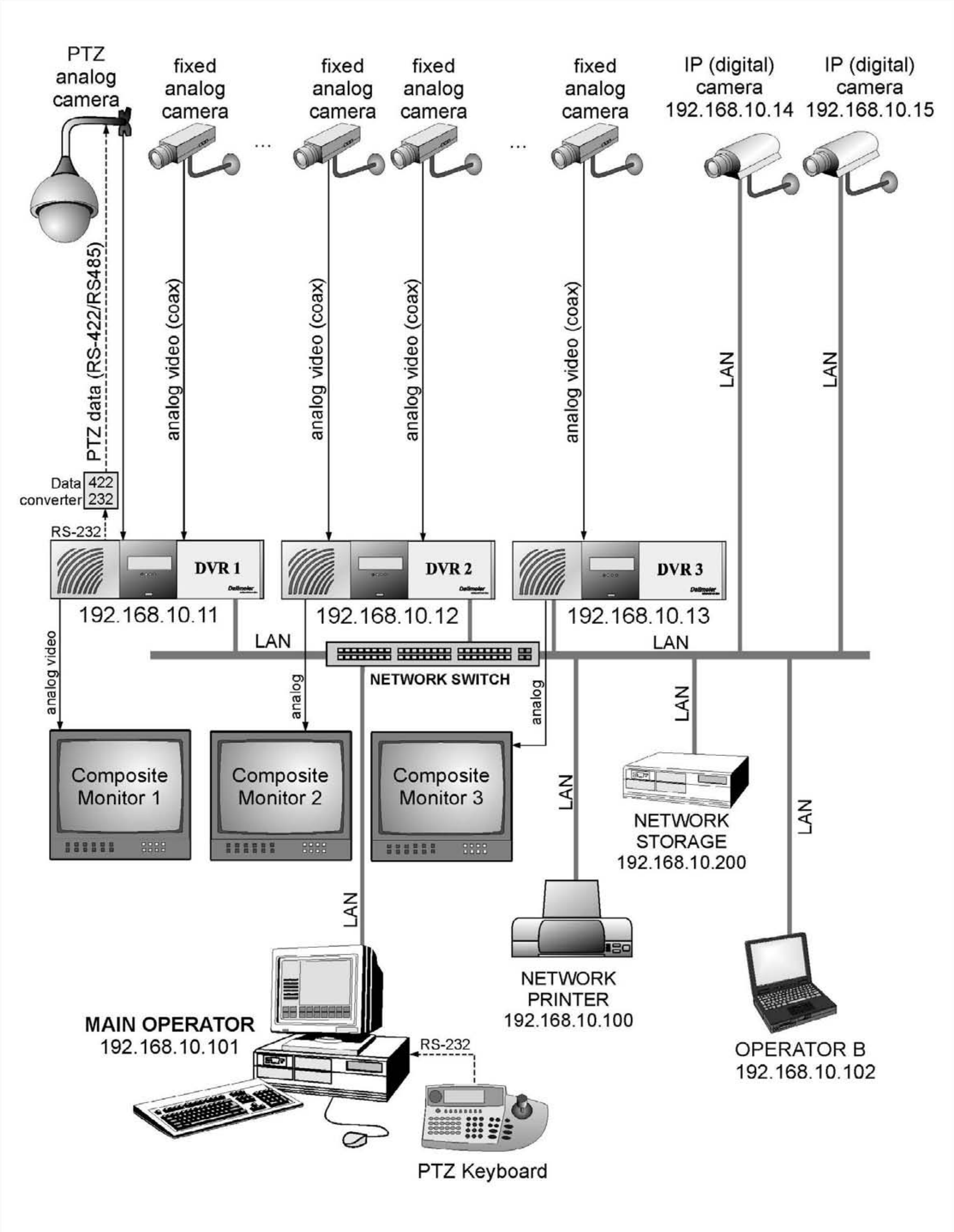
We also have depicted a PTZ camera in the system, which requires pan/tilt/zoom control from the Main Operator's console. In the drawing, we have illustrated that the main operator uses a standard CCTV keyboard, but software PTZ control from the computer is also possible, which, in our case, can be done by the Operator B.

In order to have pan/tilt/zoom control function implemented, we need to explain some things associated with PTZ data format and the transmission over networks.

It should be known that all computers (and computer-based DVRs) can use only RS-232 data format (input and output) on its serial ports (typically 2). By design, the RS-232 format is limited to a maximum of around 15 m (approximately, 50 ft) cable length. Network communications on most DVRs and IP cameras can also transmit such data while receiving images. So if the customer wishes to use a CCTV typical PTZ keyboard, then such a keyboard has to have PTZ data produced in RS-232 format, which is then fed into the Serial port (also known as Communication port) of Main Operator PC station. In order for the operator to be able to control the remote PTZ camera connected to the DVR, this data has to be transferred to the corresponding DVR with that camera. Being RS-232, this data is produced at the serial port output of that DVR. If there are more than one PTZ cameras, or the one shown in the drawing is further away than 15 m, then a data converter needs to be used at this DVR, in order to convert the RS-232 data to RS-422 or RS485, whichever is used by the particular PTZ camera. This format (RS-422/RS485) is designed to be able to reach longer distances (usually up to a kilometer, or over 3000 feet) and can address up to 32 PTZ cameras.

When the system is installed, and cables, DVRs, and cameras and set up correctly, the time comes when all these devices need to be put together to work in a seamless networked system.

Since all of these devices are connected in a LAN configuration, the first thing to do is assign each



An example system with analog and digital CCTV

Drawn by V.Damjanovski © 2004

device an IP address. The drawing shows that I have allocated each device its own address from the Private range of IP addresses. Any number can be given here, as long as they fall within the allowed Private address range.

If there are other devices on the network, which may not necessarily be part of the security system, but rather part of the company computer network, care should be taken to use addresses that are not conflicting with the security equipment IP addresses. This is the point when you would require the IT manager of the company to give you addresses from the reserved pool they may have.

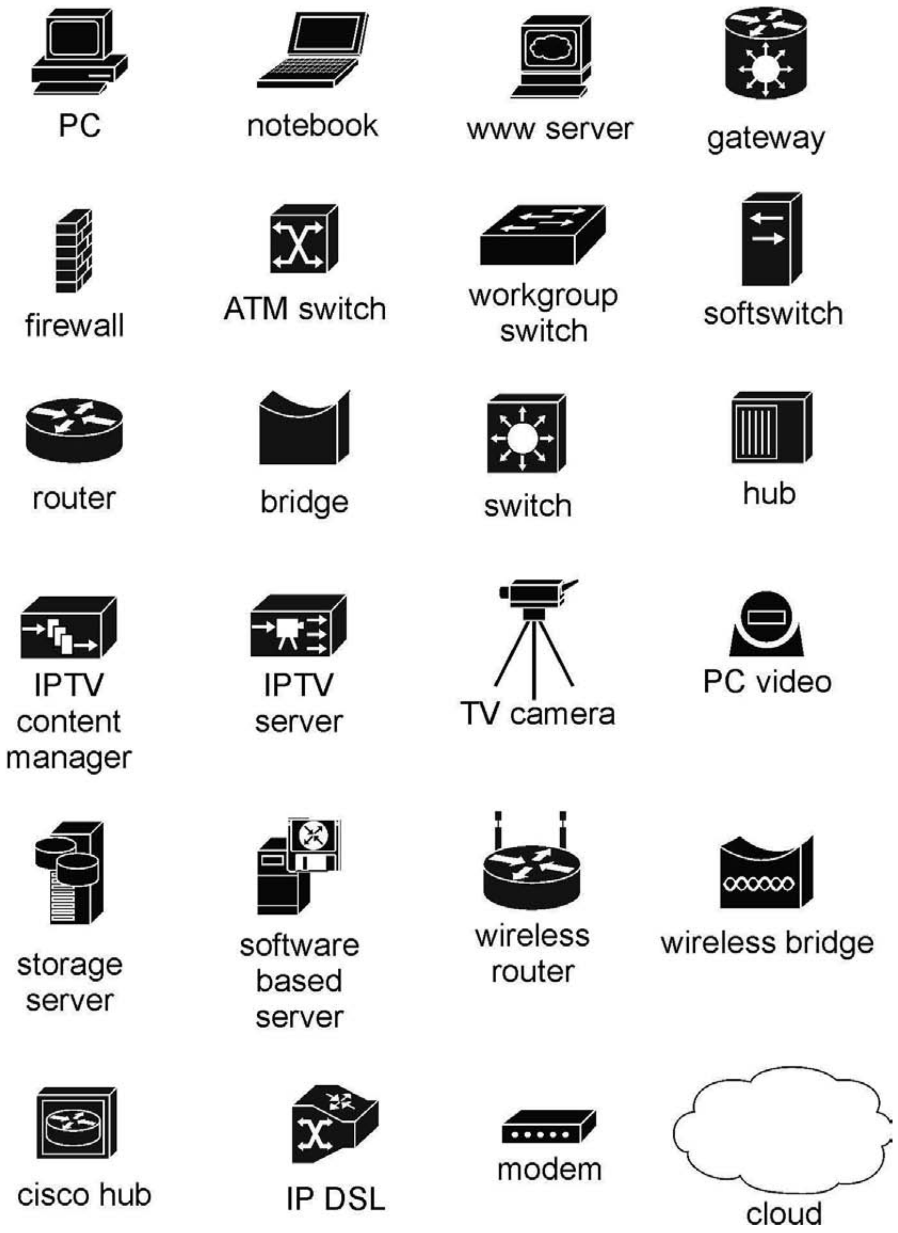
If the system is designed to utilize the customer's existing network, it should be clear that the amount of data that goes through the security system may affect the speed of the network for normal usage.

There is no easy answer as to how much this will affect the network, but it can be measured with various tools after the installation is completed. The amount of data flowing through the network clearly depends on the CCTV system design and the intended usage. If the operators are continually watching multiple split-screen images of all cameras on their computer screens, and in addition the IP cameras are continually streaming digital video in order to be stored on the NAS, then the CCTV network will be pretty busy.

It is fair to say, however, that no digital CCTV system installed on any existing network will block the normal usage that existed before the system was put in place, but it will slow it down, especially if 10 Mb/s network is used. It becomes less of an issue if the network is of a faster type (like 100 Mb/s or gigabit). In such a case, the rate of slowing down may be undetectable by a network that reads and responds to his e-mails, but for people who are transferring huge files from one computer to another, or from the Internet, for example, it may be noticeable.

For this reason, consideration should be given to using analog video monitors as display devices, instead of loading the network with unnecessary "live" image viewing. Certainly, it should be found out if the DVRs have such an output, but most of them do. If this is the case, then the operator can use the composite monitors for day-to-day surveillance activity and use the network only for playback or backing up a footage. It is also possible to have only a small number of cameras selected for viewing via the network (to save data bandwidth) and to program the DVR to bring up an image only when motion is detected. In the meantime the DVRs would usually be recording continually regardless of what display device the operator is using, so that no event is lost. Finally, many DVRs have network data bandwidth control which is used to minimize the continual streaming to the main operator's PC.

If none of the above approaches is possible (for whatever reason), then consideration should be given to designing and installing a complete, separate, and independent network dedicated just for the digital CCTV system. This might sound a bit more expensive, but it is without any doubt a better solution. The security CCTV system becomes safer and independent, but also faster as there are no other users on the network. This also gives an advantage in planning clean and fast data switching, and it is much easier to use any IP addresses one wishes to use.



Some typical network symbols as used in the IT industry

The IP check commands

Some software commands found on many platforms, Windows and Linux alike, should be known to CCTV users and could help determine whether a network device is present on the network and whether it is visible by other computers. These are the “ping” commands.

Under Windows => Start => Run type “Command” or “cmd.”



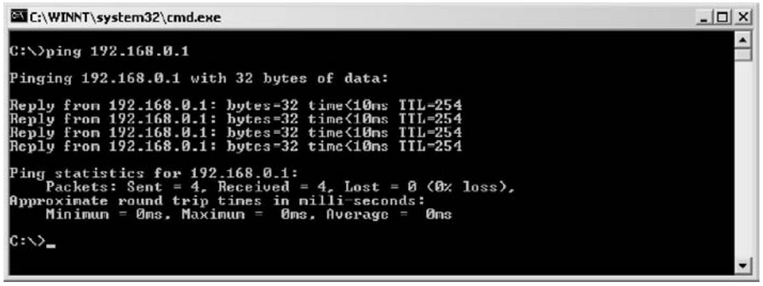
This will open a DOS window where the ping command can be typed with the IP address of the device you want to ping.

In the example shown, we typed

ping 192.168.0.1

which is the internal address of our network router.

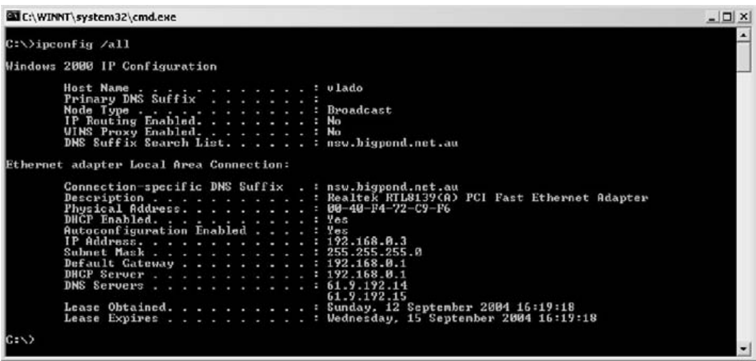
If the device is connected and has the IP address you have queried (in our example 192.168.0.1), it will respond with something similar to what is shown in the window below. The time taken to respond is shown in milliseconds (ms).



Another command that is very useful and that can give you the IP address of the computer you are logged on, as well as its physical MAC address, DNS, and DHCP, is the command:

ipconfig /all

In the example shown below, ipconfig command tells us that the computer from which we have queried the IP address has a MAC address 00-4--F4-72-C5-F6 and the IP address is 192.168.0.3. The Gateway is 192.168.0.1, and the DNS server we are connected to has the address of 61.9.192.14 and 15.



And finally, if there is a problem with the connection, the following command may indicate where the problem is:

tracert <destination address>

This command will show you the route where your ping goes and where it stops.


GEORGE ST
367 – 427
PEPSI
WALK THRU
GOWINGS
REDEVELOPMENT
RETAIL SPACE
FOR LEASE
CALL 9518 9099
SALE
GOWINGS

12. Auxiliary equipment in CCTV

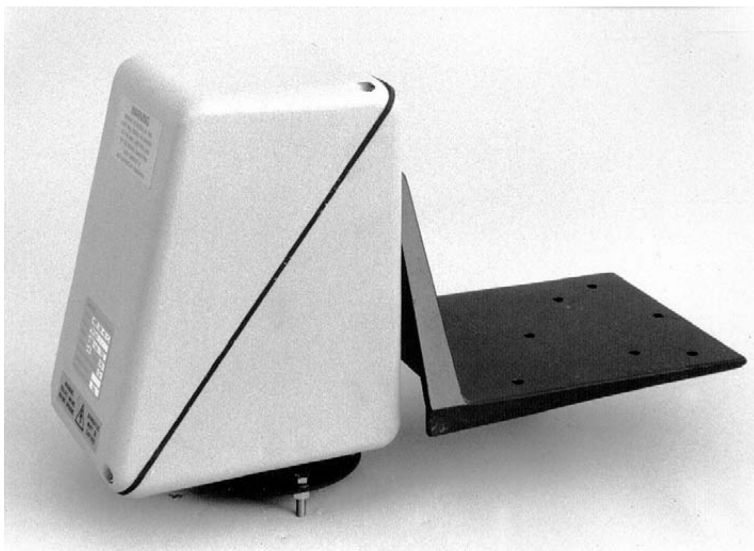
Many items in CCTV can be classified as auxiliaries. Some of them are simple to understand and use; others are very sophisticated and complex. We will start with the very popular moving mechanism, usually called ***pan and tilt head***.

Pan and tilt heads

When quoting or designing a CCTV system, the first question to ask is how many and what type of cameras: fixed or pan and tilt?

Fixed cameras, as the name suggests, are cameras installed on fixed brackets, using fixed focal length lenses and looking in the one direction without change.

The alternative to fixed are moving (or pan and tilt) cameras. They are placed on some kind of moving platform, usually employing a zoom lens, so the whole set can pan and tilt in virtually all directions and can be zoomed and focused at various distances.



A typical outdoor pan/tilt head

In CCTV terminology, this type of camera is usually referred to as a ***PTZ camera.*** Perhaps a more appropriate term would be "PTZF camera," referring to Pan/Tilt/Zoom/Focus, or even more precisely in the last few years, a "PTZFI" for an additional iris control. "PTZ camera" is, however, more popularly accepted, and we will use the same abbreviation for a camera that, apart from pan, tilt, and zoom functions, might have focus, or even iris remote control.

A typical P/T head, as shown on the picture, has a side platform for the load (a camera with a zoom lens in a housing). There are pan and tilt heads that have an overhead platform instead. The difference between the two is the load rating that each can have, which depends on the load's center of gravity. This center is lower for side platform pan and tilt heads, which means that of the two types of heads, with the same size motors and torque, the side platform has a better load rating. This should not be taken as a conclusion that the overhead platform P/T heads are of inferior quality, but it is only an observation of the load rating, which in the last few years is not as critical because camera and lens sizes, together with housings, are getting smaller.

On the basis of the application, there are two major subgroups of P/T heads:

- Outdoor
- Indoor

Outdoor P/T heads fall into one of the three categories:

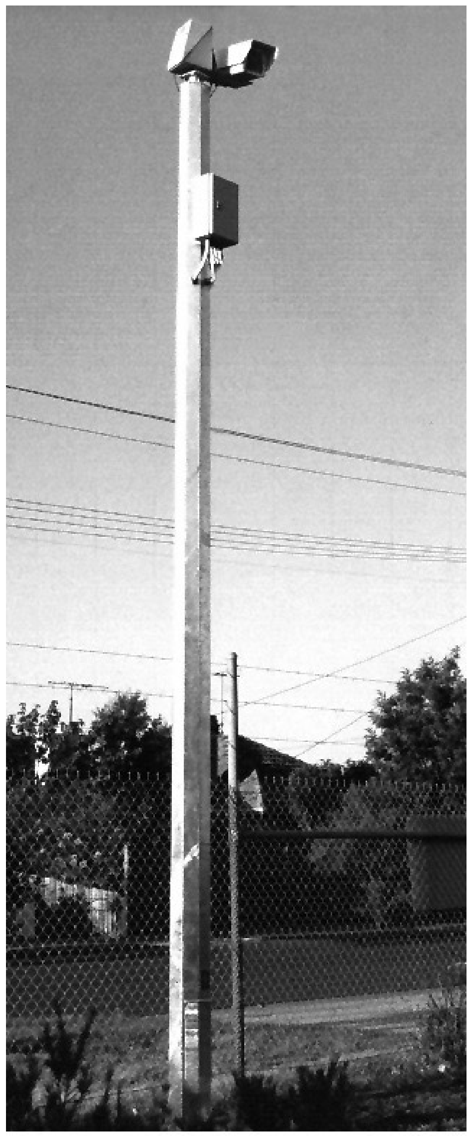
- Heavy duty (for loads of over 35 kg)
- Medium duty (for loads between 10 and 35 kg)
- Light duty (for loads of up to 10 kg)



Custom-made PT bracket

With the recent camera size and weight reductions, together with the miniaturization of zoom lenses and housings, it is very unlikely that you will need a heavy-duty P/T head these days. A medium-duty load rating will suffice in the majority of applications.

The outdoor P/T heads are weatherproof, heavier, and more robust. The reason for this is that they need to carry heavier housings and quite often additional devices such as wash/wipe assemblies and/or infrared lights.



An outdoor PTZ camera and a PTZ driver on a pole

Indoor P/T heads, as the name suggests, should only be used on premises protected from external elements, especially rain, wind and snow. Indoor P/T heads are usually smaller and lighter and in most cases they fall into the light-duty load category; they can handle loads of no more than a few kilograms. Because of this, indoor pan and tilt heads are often made of plastic molding and have a more aesthetic appearance than the outdoor ones.

In most cases, a typical P/T head is driven by 24 V AC

synchronous motors. Mains voltage P/T heads are also available (220/240 V AC or 110 V AC), but the 24 V AC is more popular because of the safety factor (voltages less than 50 V AC are not fatal to the human body) and it is more universal, regardless of whether you are working on a European, American, or Australian CCTV system. Most manufacturers have a 24 V AC version of all P/T site drivers.

Pan and tilt domes

Other divisions of pan and tilt heads, on the basis of physical appearance, are also possible. In the last few years, **pan and tilt domes** have become more popular. They work in the same way as the heads, only **inside the domes they usually have both the moving mechanism (P/T head) and the control electronics**. They are usually enclosed in a transparent or semitransparent dome, so they make an acceptable appearance in aesthetically demanding interiors or exteriors. Again, thanks to camera and lens size reductions, P/T domes are getting smaller in diameter. A few years ago, pan and tilt domes up to 1 m in diameter were not rare, while today most of them are between 300 and 400 mm.

One of the biggest problems with P/T domes is the optical precision of the dome. It is very hard to get no distortions at all, especially with heat-blown domes. Much better precision is achieved with injection molded domes, which are more expensive. Also, thicker domes cause more distortion, especially when the lens is zooming. So the best optical quality is achieved with thin and injection molded domes.



Photo courtesy of Pelco

A typical PTZ dome with built-in camera, auto focus zoom lens, pan/tilt mechanism, and site driver

A lot of manufacturers, instead of going to the trouble of producing optically nondistorting domes concentrate the optical precision on a thin vertical strip through which the camera can see and freely tilt up and down. The panning movement revolves the camera and the dome. Although this is a clever solution, it can be mechanically troublesome and a limiting factor for faster movements.

Let us also mention that domes can be transparent or neutral color tinted. Transparent domes usually have an inner mask, with an optical slot in front of the lens, while the rest of the mask is a nontransparent black plastic. By keeping the interior dark (black zoom lenses and camera bodies), they offer a very discrete and concealed surveillance. Very often it is impossible to judge where the camera is pointing, which is one of the very important features of dome cameras.



An outdoor pan/tilt dome

Tinted domes usually have no mask, and so the whole dome is transparent but tinted. It is important in such cases to know the F-stop attenuation of the tinting to compensate for the light. A typical attenuation is around one F-stop, which means 50% light attenuation. With today's CCD cameras this does not present any threat to the picture quality. The camera and zoom lens colors are more critical with this type of dome, so if they appear too obtrusive from the outside a careful black matt spray can minimize this. Utmost care should be taken, however, to protect the lens, CCD chip, and connectors from the paint.



PTZ dome camera in Sydney

Preset positioning P/T heads

Finally, another subgroup of P/T heads looks the same as all the others but are fitted with ***preset potentiometers***. They are usually referred to as ***P/T heads with PP pots***.

The potentiometers are built in the head itself, mechanically coupled with each of the motors. Their value is typically 1 kΩ or 5 kΩ and they are connected to the site driver electronics (discussed in the next chapter). A low voltage (typically 5 V DC) is applied across the pots and the site driver electronics reads the voltage drop over its center tap, depending on the pan or tilt position, thus allowing the site driver to remember the particular position, which is later recalled by either manual command or automatic alarm response.

Basically, when a site driver gets an instruction to go to a preset position, it forces the pan and tilt motors to move (the same applies to zoom and focus) until the preset potentiometers reach the preset value. So, if a certain door is protected, for example, by using a simple reed switch we can force a camera to automatically turn in that direction, zooming and focusing on the previously stored view of the door.

The number of preset positions a PTZ site can store depends on the design itself, but the most common numbers are 8, 10, 16, or 32.

A very important question is, “How precisely can the preset positions be repeatedly recalled?” This is defined by the mechanics, electronics, and the software and hardware design. The precision of preset positioning is especially important with the very fast pan and tilt units. An error of only a couple of degrees may not be noticed when a zoom lens is fully zoomed out, but it will make a big difference when it is fully zoomed in.

When ordering a pan and tilt head, you must specify that you want preset positioning. A pan and tilt head with preset potentiometers looks the same as an ordinary non-preset P/T head, because the pots are fitted inside the unit.



Almost all PTZ domes of the newer design have preset positioning.

PTZ site drivers

A very easy way of controlling a 24 V AC pan and tilt head is by simply applying 24 V to one of the motors. This means pan and tilt control can be achieved by having voltage applied to a hard-wired connection (for each of the four movement directions) relative to a common wire. So, **a total of five wires will give us full control over a typical pan and tilt head. For zoom and focus control as well, another three wires are required** (one for zoom, positive and negative voltage, one for focus, and one for common). This gives us **a total of eight wires that would be required for a so-called *hard-wired PTZ controller*.** They are the cheapest way of controlling single PTZ camera assemblies but are impractical for long distance control of over a couple of hundred meters.



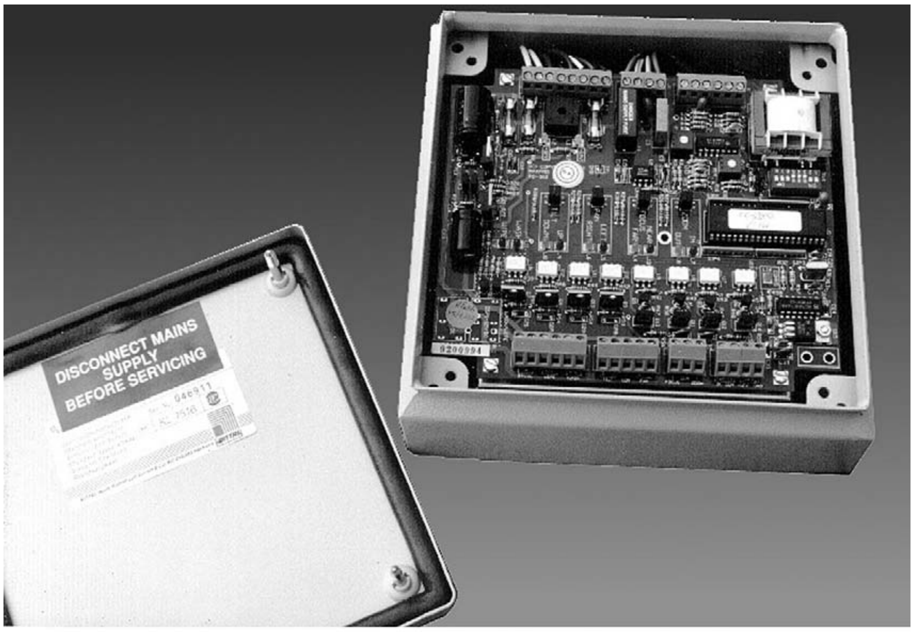
Photo courtesy of Pelco

A hard-wired PTZ controller

In the majority of CCTV systems, however, we use digital control, which only requires a twisted pair cable through which a matrix switcher can talk to a number of PTZ devices at the same time. These devices are often called **PTZ site drivers**, **PTZ decoders**, or **PTZ receiver drivers**. They are electronic boxes (discussed with video matrix switchers) that receive and decode the instructions of the control keyboard for the camera’s movements: pan, tilt, zoom, and focus (and sometimes iris as well).

As mentioned earlier, **there is unfortunately no standard among manufacturers of the control encoding schemes and protocols, which means the PTZ site driver of one manufacturer cannot be used with a matrix switcher of another.**

Depending on the site driver design, other functions might also be controllable, such as wash and wipe



A typical PTZ site driver (receiver)

and turning auxiliary devices on and off. PTZ drivers can also deliver power for the camera, either 12 V DC or 24 V AC.

The P/T heads' movement speed, when driven by 24 V AC synchronous motors (which is most often the case), depends on the mains frequency, the load on the head, and the gearing mechanism. Typical panning speeds are 9°/s and tilting 6°/s. This is closely related to the torque required to move a certain load, which in most cases exceeds 5 kg (that is: camera + zoom lens + housing). Some designs can reach a faster speed of around 15°/s pan because of camera/lens weight reductions and different gear ratios. **Most AC-driven P/T heads, which are driven by synchronous motors, have fixed speeds** because they depend on the mains frequency.

There are some advanced AC pan and tilt head site drivers where an artificial frequency, lower and higher than that of the mains, is produced for better control of the heads. A slower speed is used for finer control (when the zoom lens is fully zoomed in) and a faster speed is used for quicker response to emergency situations. The control keyboard determines the speed it should apply on the basis of the amount of time the joystick is kept pressed in any direction.



PTZ site drivers are integrated into most PTZ domes.

Even faster speeds can be achieved with DC-driven stepper motors and specially designed PTZ site drivers. Over the last few years, P/T heads (more so, P/T domes) have become much faster, exceeding 100°/s.

Producing such fast P/T assemblies brings a few problems to attention: the camera moves so quickly that an appropriate manual control is impossible, or at least impractical, and the mechanical construction

and durability are even more critical because of increased forces of inertia. When such a speed is magnified by the zoom lens magnification factor, we see already fast movement become even faster.



Larger pan/tilt domes accommodate a separate camera/lens combination.

Therefore, a novel approach to the PTZ control is now required. Such solutions can be seen in some advanced designs, achieving speeds of over 300°/s with highly accurate movement. This is achieved by combining great electronic and mechanical precision. Details like reducing the pan and tilt speed when the lens is zoomed in and increasing it when the lens is zoomed out, or having the very fast preset position speed of 300°/s drop down to a manageable 45°/s when manual control is required, make the difference between a fast and a fast-and-user-friendly system.

A preset operation is only possible with a PTZ site driver equipped with PP electronics. Clearly, both the P/T head and the zoom lens should have preset potentiometers built in.

The number of wires required between the site driver and the PTZ head is as follows: 5 wires are required for the basic pan and tilt functions as described earlier (pan left, pan right, tilt up, tilt down and common), 4 wires for pan and tilt preset positioning (positive pot supply, negative pot supply, pan feedback, and tilt feedback), 3 wires for the zoom and focus functions (sometimes 4 are required, depending on the zoom lens), and 4 wires for the zoom and focus preset positioning. This makes a **total of 16 wires**. The thickness of the preset wires and the zoom and focus wires is not critical as we have very low current for these functions, but the pan and tilt wires need to be considered carefully because they depend on the pan and tilt motors' requirements.

Let us not forget to mention that a PTZ site driver is usually installed next to the camera. There are two main reasons for this: practicality (long runs of a 16-core cable are not needed) and maintenance (one needs to see what the camera P/T head does when certain instructions are sent to the site driver).

If the situation demands however, the site driver can be up to a couple of hundred meters away from the camera itself.



Ceiling-mount dome camera

Camera housings

In order to protect the cameras from environmental influences and/or conceal their viewing direction, we use camera housings.

Camera housings can be very simple and straightforward to install and use, but they can affect the picture quality and camera lifetime if they are not well protected from rain, snow, dust, and wind or if they are of poor quality.

They are available in all shapes and sizes, depending on the camera application and length. Earlier tube cameras and zoom lenses were much bigger, calling for housings of as much as 1 m in length and over 10 kg in weight. Nowadays, CCD cameras are getting smaller, and so are zoom lenses. As a consequence, housings are becoming smaller too.



A typical outdoor camera housing

A lot of attention in the last few years has been paid to the aesthetics and functionality of the housings, such as easy access for maintenance and concealed cable entries.

With camera size reductions, these days tinted domes are used instead of housings, offering much better blending with the interior and exterior.

The glass used for housing is often considered unimportant, but optical distortions and certain spectral attenuation might be present if the glass is unsuitable. Another important factor is the toughness of the glass for camera protection in demanding environments. The optical precision and uniformity are even more critical when domes are used because the optical precision and glass (plastic) distortions are more apparent. Tinted domes are often used to conceal the camera's viewing direction. For tinted domes, light attenuation has to be taken into account. This is usually in the range of one F-stop, which is equal to half the light without the dome.



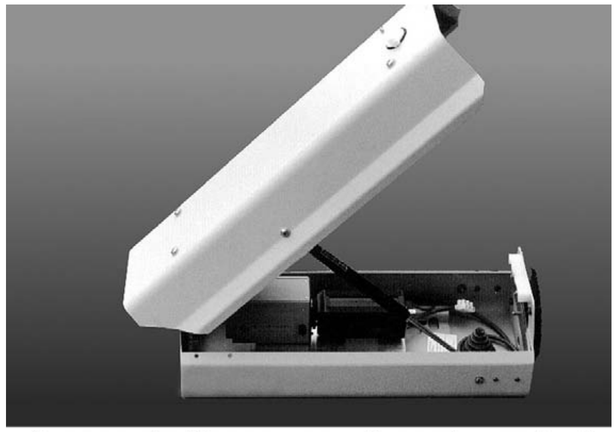
Corner-mount vandal-resistant housing

A lot of housings have provision for heaters and fans. Heaters might be required in areas where a lot of moisture, ice, or snow is expected. Usually, about 10 W of electrical energy is sufficient to produce enough heat for a standard housing interior. The heaters can work on 12 V DC, 24 V AC, or even mains voltage. Check with the supplier before connecting. No damage will occur if a 240 V (or even 110 V) heater is connected to 24 V (however, sufficient heat will not be produced), but the opposite is not recommended. Also, avoid primitive improvisations without any calculations, such as connecting two 110 V heaters in series to replace a single 240 V heater (110 + 110 = 220). The little bit of

difference (240 V instead of 220 V) is enough to produce excessive heat and cause a quicker burning of the heater and may even cause a fire.

In case a heater is required for an already installed housing, it is relatively easy to simulate one with a resistor of 30 to 50 Ω and 20 W power rating (for 24 V AC). As a circuit break element, an N/C thermostat, with a low switch-on temperature, can be used. Do not forget though, that the camera, having a power rating of a couple of watts, acts as a heater and if the housing is small and well sealed, this should create sufficient heat to dry the moisture inside. For snowy areas, however, a proper heater is needed, mounted close to the housing glass.

Fans should be used in areas with very high temperatures, and sometimes they can be combined with heaters. The voltage required for the fan to work can also be DC or AC, but be sure to use good-quality fans, as most of the DC fans will sooner or later produce sparks from the brushes when rotating, which will interfere with the video signal.



Access to the camera is an important consideration for the type of housing.

So heaters and fans are an extra obligation, but if you have to have them, make sure you provide them with the correct and sufficient power. They are usually set to work automatically with a rise or fall in temperature (i.e., there is no need for manual control).

Special housings are required if a ***wash and wipe*** assembly is to be added to the PTZ camera. They are special because of the matching required between the wipe mechanism and the housing window. It should be pointed out that when the wash/wipe assembly is used, the PTZ driver needs to have output controls for these functions as well. They might be 24 V, 220 ~ 240 V, or 110 V AC. Another responsibility when using washers is to make sure that the washer bottle is always filled with a sufficient amount of clean water.



Special liquid-cooled housing for up to 1300° C

Housings and boxes (such as PTZ site drivers) that are exposed to environmental influences are rated with the IP numbers. These numbers indicate to what degree of shock, dust, and water aggression the box is resistant.

Most camera housings are well protected from the environment, but in special system designs, even better protection might be required. ***Vandal-proof housings*** are required in systems where human or vehicle intervention is predicted, so a special, toughened (usually lexan) glass needs to be used, together with special locking screws. Tamper switches may also be added for extra security. In cases like that,

Meaning of IP ratings

IP	First number: *Protection against solid objects*	IP	Second number: *Protection against liquids*	IP	Third number: *Protection against mechanical impacts*
0	No protection of the electrical equipment	0	No protection of the electrical equipment	0	No protection of the electrical equipment
1	Protected against solid objects up to 50mm, e.g., accidental touch by hands	1	Protected against vertical falling drops of water	1	15cm, 150g – Impact 0.225 Joules
2	Protected against solid objects over to 12mm, e.g., fingers	2	Protected against direct sprays of water up to 15º from the vertical	2	15cm, 250g – Impact 0.375 Joules
3	Protected against solid objects over 2.5mm (tools, wires)	3	Protected against direct sprays of water up to 60º from the vertical	3	20cm, 250g – Impact 0.50 Joules
4	Protected against solid objects over 1mm (tools, wires, small wires)	4	Protected against water sprayed from all directions – limited ingress permitted	4	N / U
5	Protected against dust-limited ingress (no harmful deposit)	5	Protected against low pressure jets of water from all directions – limited ingress permitted.	5	40cm, 500g – Impact 2 Joules
6	Totally protected against dust	6	Protected against strong jets of water, e.g., for use on shipdecks – limited ingress permitted	6	N / U
		7	15cm - 1m – Protected against the effects of immersion between 15cm and 1m	7	40cm, 1500g – Impact 6 Joules
		8	Protected against long periods of immersion under pressure	8	N / U
				9	40cm, 5kg – Impact 20 Joules

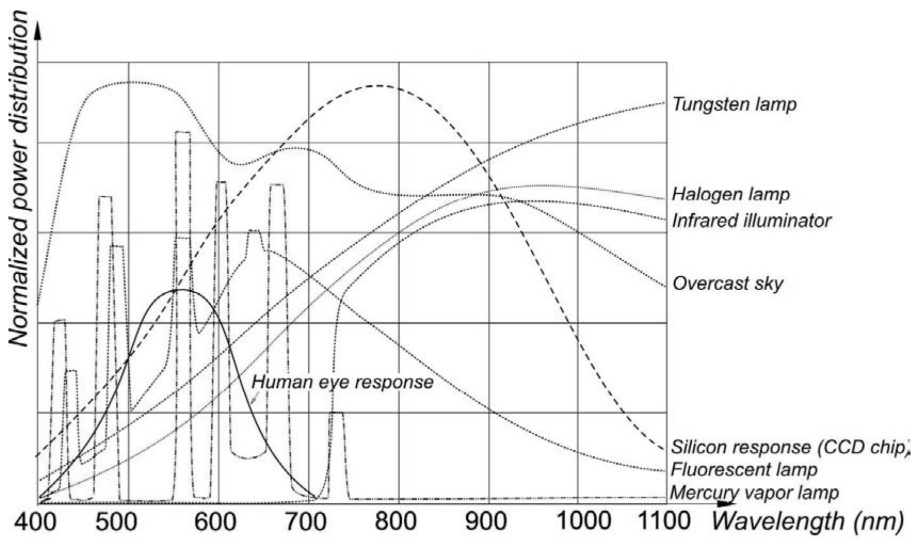
IP Ratings for protection from dust, water and impact of electrical equipment for voltages of up to 1000 V AC and 1200 V DC, as per RS data.

the tamper alarm has to come back to the control center, usually through the PTZ driver, providing it has such a facility.

And last, ***bullet-proof***, ***explosion-proof,*** and ***underwater housings*** are also available, but they are very rare, specially built, and very expensive. We will therefore not dedicate any space to them in this book, but should you need more details contact your local supplier.

Lighting in CCTV

Most of the CCTV systems with outdoor cameras use both day and night light sources for better viewing. Systems for indoor applications use, obviously, indoor (artificial) light sources, although some may mix with daylight, as when sunlight penetrates through a window.



Spectral energy dissipation of various light sources

The sun is our daylight source, and as mentioned earlier, the light intensity can vary from as low as 100 lx at sunset to 100,000 lx at noon. The color temperature of sunlight can also vary, depending on the sun's altitude and the atmospheric conditions, such as clouds, rain, or fog. This might not be critical for B/W cameras, but a color system will reflect these variations.

Artificial light sources fall into three main groups, according to their spectral power content:

1. Sources that emit **radiation by incandescence**, such as candles, tungsten electric lamps, and halogen lamps.

2. Sources that emit radiant energy as a result of an **electrical discharge through a gas or vapor**, such as neon lamps and sodium and mercury vapor lamps.

3. **Fluorescent tubes**, in which a gas discharge emits visible or ultraviolet radiation within the tube, causing phosphors on the inside surface of the tube to glow with their own spectrum.

The light sources of the first group produce a **smooth and continuous light spectrum** as per the Max Planck formula, similar to the black body radiation law. These light sources are very suitable for B/W cameras because of the similarity in the spectrums, especially on the left side of the CCD chip spectral response.

The second group of light sources produces almost discrete components of particular wavelengths, depending on the gas type.

The third group has a more continuous spectrum than the second one, but it still has components of significant levels (at particular wavelengths only), again, depending on the type of gas and phosphor used.

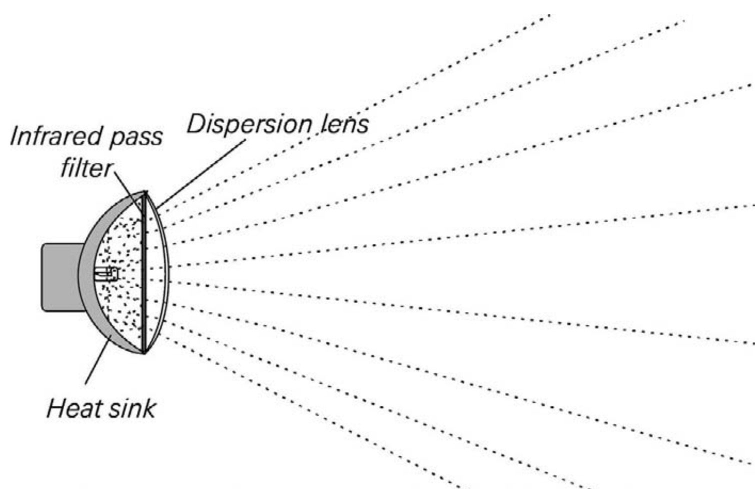
The last two groups are very tricky for color cameras. Special attention should be paid to the color temperature and white balance capability of the cameras used with such lights.

Infrared lights

When events need to be monitored at night, B/W cameras can be used in conjunction with infrared illuminator(s). Infrared light is used because B/W CCD cameras have very good sensitivity in and near the infrared region. These are the wavelengths longer than 700 nm. As mentioned at the beginning of this book, the human eye can see up to 780 nm, with the sensitivity above 700 nm being very weak, so in general we say that the human eye only sees up to 700 nm.

Monochrome CCD chips see better in the infrared portion of the spectrum than the human eye. The reason for this is the nature of the photo-effect itself. Longer wavelength photons penetrate the CCD structure more deeply. The infrared response is especially high with B/W CCD chips without an infrared cut filter.

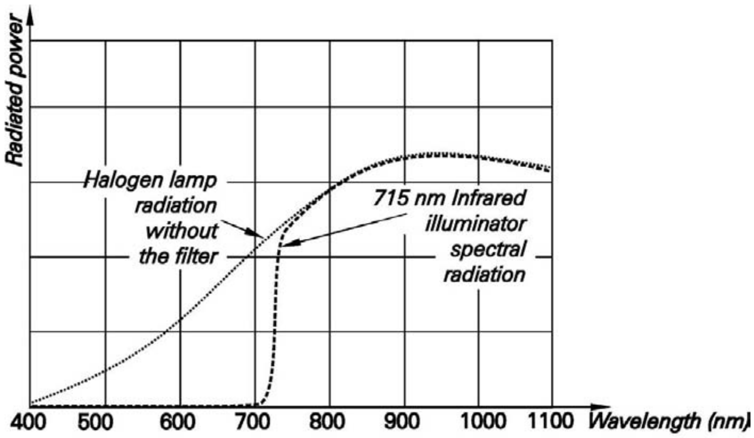
A few infrared light wavelengths are common to CCTV infrared viewing. Which one is to be used and in what case depends first on the camera's spectral sensitivity (various chip manufacturers have different spectral sensitivity chips) and, second, on the purpose of the system.



Cross section of an infrared illuminator

The two typical infrared wavelengths used with **halogen lamp illuminators** are: one starting from around 715 nm and the other from around 830 nm.

If the idea is to have infrared lights that will be visible to the public, the 715 nm wavelength is the better choice. If night-time hidden surveillance is wanted, the 830 nm wavelength (which is invisible



Infrared pass filter

to the human eye) should be used.

The halogen lamp infrareds come in two versions: 300 W and 500 W. The principle of operation is very simple: a halogen lamp produces light (with a similar spectrum as the black body radiation), which then goes through an ***optical high-pass filter***, blocking the wavelengths shorter than 715 nm (or 830 nm). This is why we say wavelengths **starting** from 715 nm or **starting** from 830 nm. The infrared radiation is **not one frequency only but a continuous spectrum starting from the nominated wavelength.**

The energy contained in the wavelengths that do not pass the filter is reflected back and accumulated inside the infrared illuminator. There are heat sinks on the IR light itself that help cool down the unit, but still, the biggest reason for the short MTBF (1000–2000 hr) of the halogen lamp is the excessive heat trapped inside the IR light.

The same description applies to the 830 nm illuminators; only in this case we have infrared frequencies invisible to the human eye. As mentioned earlier, 715 nm is still visible to many.

These infrared illuminators pose a certain danger, especially for installers and maintenance people. The reason for this is that the human eye's iris stays open since it does not see any light, so blindness could result. This can happen only when one is very close to the illuminator at night, which is when the human eye's iris is fully opened.

The IR photo cell, being active at night, turns the light on.

The best way to check that the IR works is to feel the temperature radiation with your hand; human skin senses heat very accurately. Remember, heat is nothing but infrared radiation.

The infrared illuminators are mains operated, and photo cells are used to turn them on when daylight falls below a certain level.

Both types of halogen infrared illuminators mentioned come with various types of dispersion lenses, and it is desirable to know what angle of coverage is best for a situation. If the infrared beam is concentrated to a narrow angle, the camera can see farther, provided a corresponding narrow angle lens is used (or a zoom lens is zoomed in).



IR illuminators usually go in pairs.

Halogen lamp infrared lights offer the best illumination possible for a B/W CCD chip, but their short lifespan has initiated new technologies, one of which is the concept of ***solid-state infrared LEDs*** (Light-Emitting Diodes) mounted in the form of a matrix. This type of infrared is made with high-luminosity infrared LEDs, which have a much higher efficiency than standard diodes and radiate a considerable amount of light. Such infrared lights come with a few different power ratings: 7 W, 15 W, and 50 W. They are not as powerful as the halogen ones, but the main advantage is their MTBF of over 100,000 hr (20 to 30 years of continuous night operation).



A solid-state IR

How far you can see with such infrareds depends, again, on the camera in use and its spectral characteristics. It is always advisable to conduct a site test at night for the best understanding of distances.

The angle of dispersion is limited to the LED's angle of radiation, which usually ranges between about 30° and 40°, if no additional optics are placed in front of the LED matrix.

Another type of IR used in applications is an ***infrared LASER diode*** (LASER = light amplification by stimulated emission of radiation). Perhaps not as powerful as the LEDs, but with a laser source, the wavelength is very clean and coherent. A typical LASER diode radiates light in a very narrow angle, so a little lens is used to disperse the beam (usually up to about 30°). Lasers use very little power. They concentrate coherent light into one beam, but their MTBF is shorter than the LEDs, and it usually goes up to about 10,000 hr (approximately two to three years of continuous night operation). The major advantages of the LASER infrared light are its very low current consumption and its small size.

We need not mention that **color cameras cannot see infrared light** owing to the spectrum filtering of their infrared cut filter. There are, however, camera manufacturers that have come up with some innovative ideas of using a color CCD chip setup for day viewing and at night converting the same chip to monochrome by removing the infrared cut filter.

Others use a simpler method, which is to place two chips (one color and the other B/W) in the one camera body, where the light is split by a semitransparent mirror.

Ground loop correctors

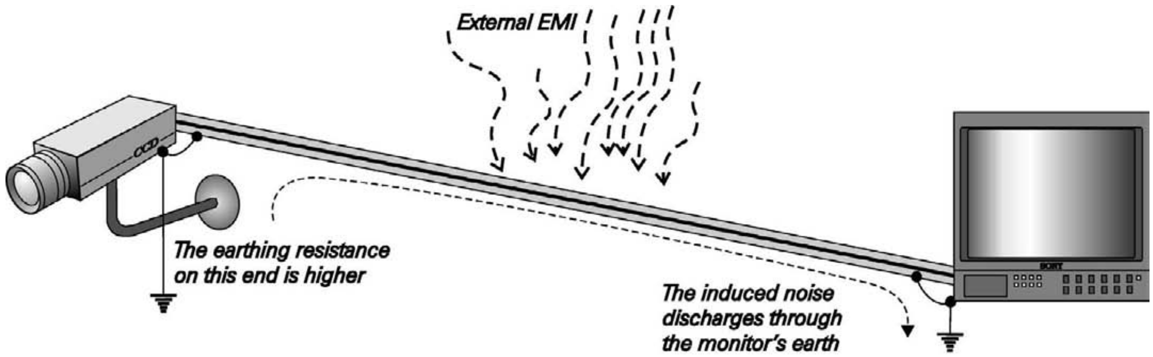
Even if all precautions have been taken during installation, problems of a specific nature often occur: ***ground loops***.

Ground loops are an unwanted phenomenon caused by the ground potential difference between two distant points. It is usually the difference between the camera and the monitor point, but it could also be between a camera and a switcher, or two cameras, especially if they are daisy-chained for synchronization purposes. The picture appears wavy and distorted. Small ground loops may not be noticeable at all, but substantial ones are very disturbing for the viewers. When this is the case, the only solution is to galvanically isolate the two sides. This is usually done with a video **isolation transformer**, sometimes called a ***ground loop corrector*** or even a ***hum bug*** unit.

Ground loops can be eliminated, or at least minimized, by using monitors or processing equipment with ***DC restoration***. The DC restoration is performed by the input stage of a device that has DC restoration, where the "wavy" video signal is sampled at the sync pedestals so as to regenerate a "straight" DC level video signal. This in effect eliminates low-frequency induction, which is the most common ground loop artifact. A better solution, though a more expensive one, is the use of a fiber optics cable instead of a coaxial, at least between the distant camera(s) and the monitor end.



A ground loop corrector



Ground loop

Lightning protection

Lightning is a natural phenomenon about which there is not much we can do. PTZ sites are particularly vulnerable because they have video, power and control cables concentrated in the one area. **A good and proper earthing is strongly recommended** in areas where intensive lightning occurs, and of course surge arresters (also known as spark or lightning arresters) should be put inside all the system channels (control, video, etc.). Most good PTZ site drivers have **spark arresters** built in at the data input terminals and/or galvanic isolation through the communication transformers.

Spark arresters are special devices made of two electrodes, which are connected to the two ends of a broken cable, housed in a special gas tube that allows excessive voltage induced by lightning to discharge through it. They are helpful, but they do not offer 100% protection.

An important characteristic of lightning is that it is dangerous not only when it directly hits the camera or cable but also when it strikes within close range. The probability of having a direct lightning hit is close to zero. The more likely situation is that lightning will strike close by (within a couple of hundred meters of the camera). The induction produced by such a discharge is sufficient to cause irreparable damage. Lightning measuring over 10,000,000 V and 1,000,000 A is possible; imagine the induction it can create.

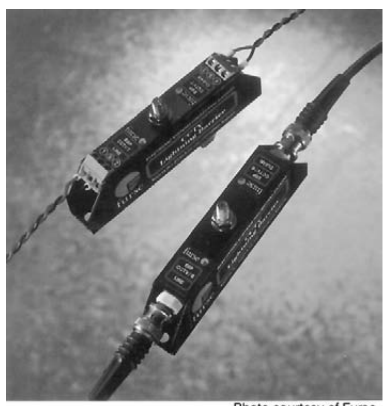


Photo courtesy of Furse

Lightning protectors

Again, as with the ground loops, the best protection from lightning is using a fiber optics cable; with no metal connection, no induction is possible.

In-line video amplifiers/equalizers

When coaxial cables are used for video transmission of distances longer than what is recommended for the particular coax, ***in-line amplifiers*** (sometimes called ***video equalizers*** or ***cable compensators***) are used.

The role of an in-line amplifier/equalizer is very straightforward: **it amplifies and equalizes the video signal**, so by the time it gets to the monitor end it is restored, more or less, to the levels it should be when a camera is connected to a monitor directly next to it.

If no amplifier is used on long runs, the total cable resistance and capacitance rise to the values where they affect the video signal considerably, both in level and bandwidth. When using a couple hundred meters of coaxial cable (RG-59), the video signal level can drop from the normal 1 V_{pp} down to 0.2 or 0.3 V_{pp}. Such levels become unrecognizable to the monitor (or VCR). As a result, the contrast is very poor, and the syncs are low, so the picture starts breaking and rolling. In addition, the higher frequencies are attenuated much more than the lower ones, which is reflected in the loss of fine details in the video signal. From fundamental electronics it is known that higher frequencies are always attenuated more because of various effects such as the skin effect or impedance-frequency relation, to name just two.

This is why equalization of the video signal spectrum is necessary and not just the amplification of it.

Obviously, with every amplification stage the noise is also amplified. That is why there are certain guidelines, with each in-line amplifier/equalizer, that need to be followed. Theoretically, it would be best if the amplifier/equalizer is inserted in the middle of the long cable run, where the signal is still considerably high relative to the noise level. However, the middle of the cable is not a very practical place, mainly because it requires power and mounting somewhere in the field or under the ground.



Video equalizer/amplifier

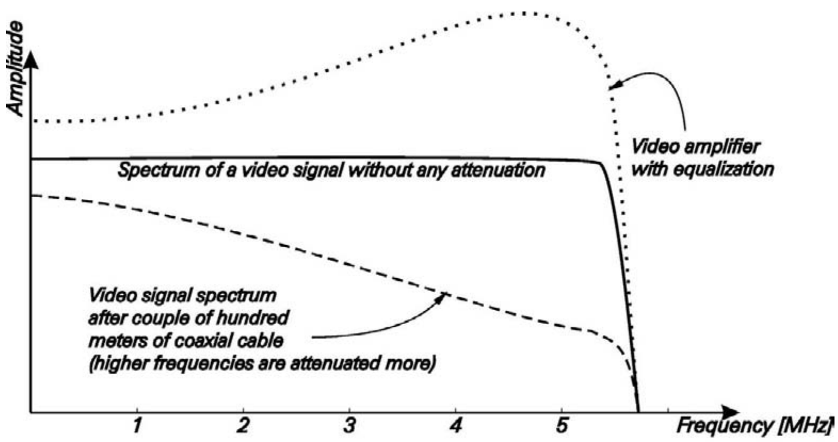
This is why most manufacturers suggest one of the two other alternatives.

The first and most common alternative is to install the in-line amplifier at the camera end, often in the camera housing itself. In such a case, we actually do a **pre-amplification and pre-equalization**, where the video signal is boosted up and equalized to unnatural levels, so that by the time it gets to the receiving end (the distance should be roughly known), it drops down to 1V_{PP}.

The second installation alternative is to place the amplifier at the monitor end, where more noise will accumulate along the length, but the amplification can be controlled better and needs to be brought up from a couple of hundred millivolts to a standard 1 V_{pp}. This might be more practical in installations

where there is no access to the camera itself.

In both of the above alternatives, a potentiometer is usually available at the front of the unit, with calibrated positions for the cable length to be compensated. In any case, it is of great importance to know the cable length being compensated for.



Video amplification/equalization

A number of in-line amplifiers can be used in series, that is, if 300 m of RG-59/U is the maximum recommended length for a B/W signal, 1 km can be reached by using two amplifiers (some manufacturers may suggest only one for runs longer than a kilometer) or maybe even three. Note: **the noise cannot be avoided, and it always accumulates**. Furthermore, the risk of ground loops, lightning, and other inductions, with more (two or three) in-line amplifiers, will be even greater.

Again, if you know in advance that your installation has to go over half a kilometer, the best suggestion is to use fiber optics. Many would suggest an RG-11/U coaxial cable instead, where a single run, without an amplifier, can go up to 600 – 700 m, but the cost of fiber optics these days is comparable to, if not lower than, the RG-11/U. We have already covered the many advantages of fiber.

Video distribution amplifiers (VDAs)

Very often, a video signal has to be taken to a couple of different users: a switcher, a monitor, and another switcher or quad, for example. This may not be possible with all of these units because not all of them have the looping video inputs. Looping BNCs are most common on monitors. Usually, there is a switch near the BNCs, indicated with “75 Ω” and “High” positions. This is a so-called ***passive input impedance matching***. If you want to go to another device, a monitor, for example, the procedure is to switch the first monitor to ***High Impedance*** and loop the coaxial cable to the second monitor, where the impedance setting should be at 75 Ω.



Photo courtesy of Pelco

Video distribution amplifier

This is important, as we discussed earlier, because a **camera is a 75 Ω source and it has to see 75 Ω at the end of the line in order to have a correct video transmission with 100% energy transfer** (i.e., no reflections).

Now picture a situation, very common in CCTV, where a customer wants to have two switchers at two different locations, switching the same cameras but independently from each other. This can easily be solved by using two video switchers, one looping and the other terminating, where we can use the same logic as with the monitors.

In practice, however, simple and cheap switchers are usually made with just one BNC per video input, which means that they are ***terminating inputs*** (i.e., with 75 Ω input impedance and looping).

It would be wrong to use BNC T adaptors to loop from one switcher to another, as many installers do. This is incorrect because then we will have two 75 Ω terminations per channel, so the video cameras will see incorrect impedance, causing partial reflection of the signals, in which case the reproduction will be with double imaging and incorrect dynamics.

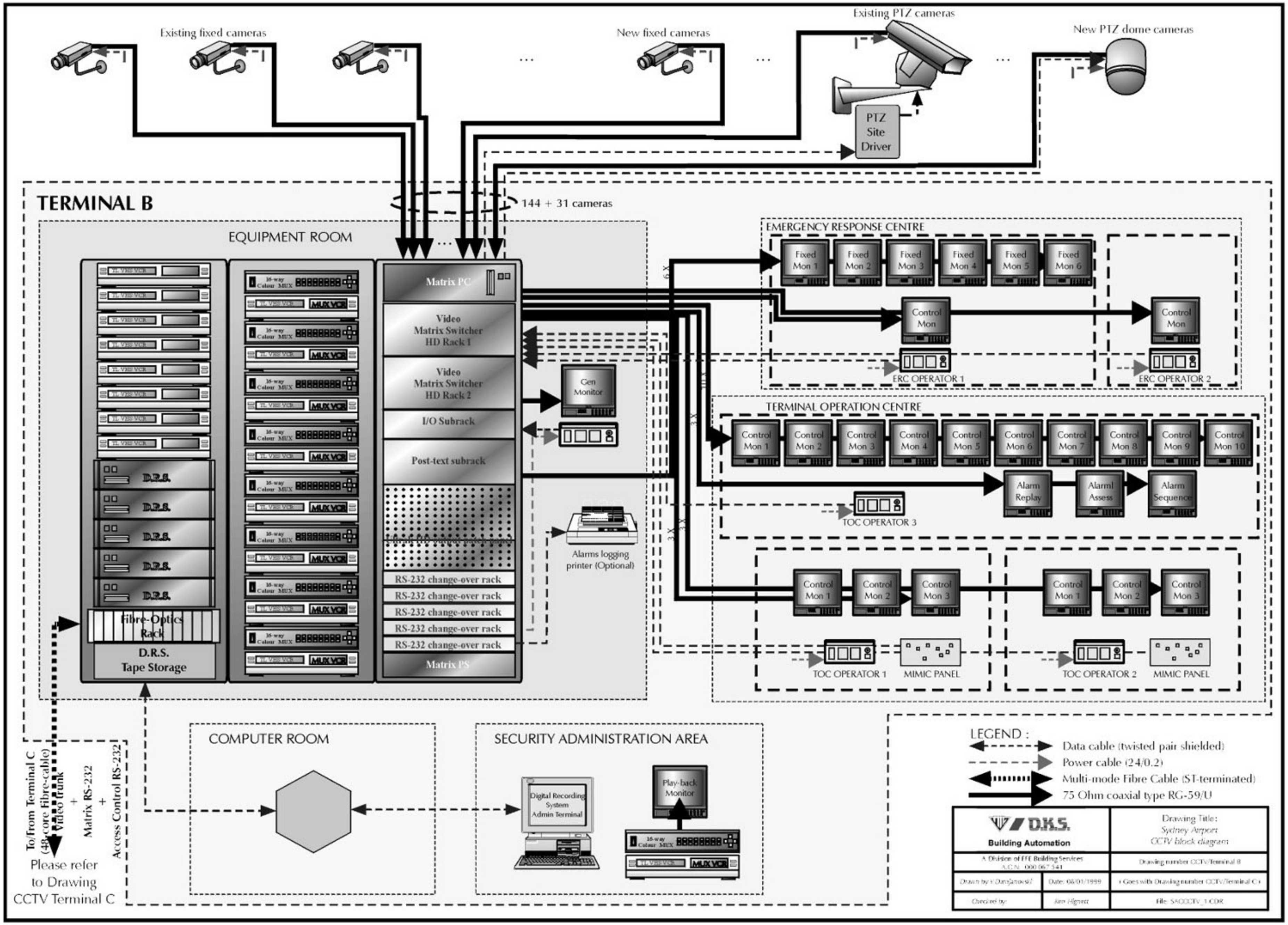
The solution for these sorts of cases is the use of the ***video distribution amplifier*** **(VDA)**. VDAs do exactly what the name suggests – they distribute one video input to more outputs, preserving the necessary impedance matching. This is achieved with the use of some transistors or op-amp stages. Because active electronics is used (where power needs to be brought to the circuit), this is called ***active impedance matching***.



BNC T-piece

A typical VDA usually has one input and four outputs, but models with six, eight, or more outputs are available as well. One VDA is necessary for each video signal, even if not all four outputs are used.

Video matrix switchers use the same concept as the VDAs when distributing a single video signal to many output channels. In such a case, only a limited number of VDA stages can be used in bigger matrix systems. This is because every new stage injects a certain amount of noise, which with analog signals cannot be avoided.



Existing fixed cameras
New fixed cameras
Existing PTZ cameras
New PTZ dome cameras
PTZ Site Driver
TERMINAL B
144 + 31 cameras
EQUIPMENT ROOM
Matrix PC
Video Matrix Switcher HD Rack 1
Video Matrix Switcher HD Rack 2
I/O Subrack
Post-text subrack
RS-232 change-over rack
RS-232 change-over rack
RS-232 change-over rack
RS-232 change-over rack
RS-232 change-over rack
Matrix PS
D.R.S.
D.R.S.
D.R.S.
D.R.S.
D.R.S.
Fibre-Optics Rack
D.R.S. Tape Storage
Gen Monitor
Alarms logging printer (Optional)
EMERGENCY RESPONSE CENTRE
Fixed Mon 1
Fixed Mon 2
Fixed Mon 3
Fixed Mon 4
Fixed Mon 5
Fixed Mon 6
Control Mon
Control Mon
ERC OPERATOR 1
ERC OPERATOR 2
TERMINAL OPERATION CENTRE
Control Mon 1
Control Mon 2
Control Mon 3
Control Mon 4
Control Mon 5
Control Mon 6
Control Mon 7
Control Mon 8
Control Mon 9
Control Mon 10
Alarm Replay
Alarm Assess
Alarm Sequence
TOC OPERATOR 3
Control Mon 1
Control Mon 2
Control Mon 3
TOC OPERATOR 1
MIMIC PANEL
Control Mon 1
Control Mon 2
Control Mon 3
TOC OPERATOR 2
MIMIC PANEL
To/from Terminal C (48 core Fibre-cable)
Video trunk + Matrix RS-232 + Access Control RS-232
Please refer to Drawing CCTV Terminal C
COMPUTER ROOM
SECURITY ADMINISTRATION AREA
Digital Recording System Admin Terminal
Play-back Monitor
LEGEND :
Data cable (twisted pair shielded)
Power cable (24/0.2)
Multi-mode Fibre Cable (ST-terminated)
75 Ohm coaxial type RG-59/U
D.K.S.
Building Automation
Drawing Title:
Sydney Airport
CCTV block diagram
Date: 08/01/1999

13. CCTV system design

Designing a CCTV system is a complex task, requiring at least basic knowledge of all the stages in a system, as well as its components. But more importantly, prior to designing the system, we need to know what the customer expects from it.

Understanding the customer's requirements

The first and most important preparation before commencing the design is to **know and understand the customer's requirements**. Customers can be technically oriented people, and many understand CCTV as well as you do, but most often they are not aware of the latest technical developments and capabilities of each component.

The most important thing to understand is the general concept of the surveillance the customer wants: constant monitoring of cameras and activities undertaken by 24-hour security personnel, or perhaps just an unattended operation (usually with constant recording), or maybe a mixture of the two. Once you understand their general requirements, it might be a good idea to explain to them what is achievable with the equipment you would be suggesting. This is reasonably easy to accomplish with smaller and simpler systems, but once they grow to a size of more than 10 cameras some of which could be PTZs, a few monitors, more than one control point, a number of alarms, VCRs, and the like, things will get tougher.

Many unknown variables need to be considered: What happens if a number of alarms go off simultaneously? Which monitor should display the alarms? Will the alarms be recorded if the VCR(s) is/are playing back? What is the level of priority for each operator? And so on.

Those are the variables that define the system complexity and as in mathematics, in order to solve a system with more variables, one needs to know more parameters. They can be specified by the customer, but only after the customer has understood the technical capabilities of the equipment.

Understandably, it is imperative for you, as a CCTV expert, to know the components, hardware, and software you would be offering and to achieve what is required in the best possible way.

You can create a favorable impression in the customer's mind if at the end you give him or her as much as, or even more than, what you have promised. You will prove unsatisfactory if you do not. Remember that if the customer is fully satisfied the first time, chances are he or she will come back to do business with you again.

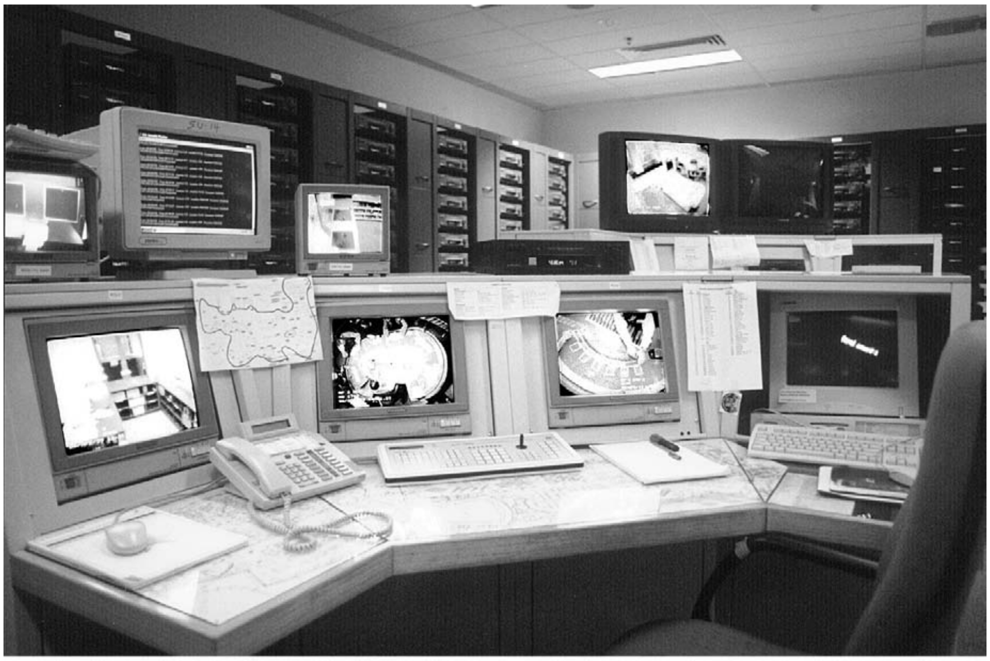


Talking and listening to customers is very important.

To put it simply: Do not claim the system will do this and that if you are not certain; make sure your system delivers what you say it will.

So, to design a good, functional system, one has to know the components used, their benefits and limitations, how they interconnect, and how the customer wants them to be used.

The first few parts are assumed to be fulfilled, since you would not be doing that job unless you knew a few things about CCTV. The last one – what the customer wants – can be determined during the first phone call or meeting.



Sydney's Star City Casino CCTV control console

Usually, the next step is to conduct a site inspection. Here is a short list of questions you should ask your customer prior to designing the system and before or during the site inspection:

• What is the main purpose of the CCTV system?

If it is a deterrent, you need to plan for cameras and monitors that will be displayed to the public. If it is a concealed surveillance, you will need to pay special attention to the camera type and size, its protection, concealed cabling, and the like, as well as when it is supposed to be installed (after hours perhaps).

• Who will be the operator(s)?

If a dedicated 24 hour guard is going to use the system, the alarm response needs to be different from that expected when unattended, or a partially attended, system operation.

• Will it be a monochrome or color system?

The answer to this question will dictate the price, as well as the minimum illumination response. Consequently, the lighting in the area needs to be looked at. A color picture will give more details about the observed events, but if the intention is to see images in very low light levels, or with infrared lights, there is no other alternative but B/W cameras (unless the customer is prepared to pay for some of the new cameras available on the market that switch between color and monochrome operation).

The price of a color system is dictated not only by the cameras, but also by the monitors,

multiplexers, and/or quads (if any). Needless to say, sequential or matrix switchers, as well as time-lapse VCRs, are the same for both B/W and color.

• How many cameras are to be used?

A small system with up to half a dozen cameras can be easily handled by a switcher or multiplexer, but bigger systems usually need a matrix switcher or a larger number of switchers and multiplexers.

• How many of the cameras will be fixed focal length and how many PTZ?

There is a big difference in price between the two because if a PTZ camera is used instead of a fixed one, the extra cost is in the zoom lens (as opposed to the fixed one), the pan and tilt head or dome, the site driver, and the control keyboard to control it. But the advantages your customer will get having a PTZ camera will be quadrupled. If on top of this, preset positioning PTZ cameras are used, the system flexibility and efficiency will be too great to be compared with the fixed camera system. A system with only one PTZ camera and half a dozen fixed ones is a choice that may require a matrix switcher for control and will increase the price dramatically (compared to a system with only fixed cameras). Alternatively, single PTZ camera control can be achieved via a special single-camera digital or hard-wired controller, but they would also increase the price considerably. So, if a PTZ camera is required, it would be more economical to have more than one PTZ camera.

• How many monitors and control keyboards are required?

If it is a small system, one monitor and keyboard is the logical proposal, but once you get more operators and/or channels to control and view simultaneously, it becomes harder to plan a practical and efficient system. Then, an inspection of the control room is necessary in order to plan the equipment layout and interconnection.



A well-designed control console

• Will the system be used for live monitoring (which will require an instant response to alarms), or perhaps recording of the signals for later review and verification?

This question will define whether you need to use VCR(s) with multiplexer(s). If you have a matrix switcher, you will still need a multiplexer or two in addition. Have in mind that the time lapse mode you are going to use depends on how often the tapes can be changed, and this defines the update rate of each camera recorded. Choose, whenever possible, a pair of 9-way (or 8-way) multiplexers instead of one 16-way, if you want to minimize the time delay in the recording rate update.

• What transmission media can be used on the premises?

Usually, a coaxial cable is taken as an unwritten rule and installation should be planned accordingly. Sometimes, however, there is no choice but to use a wireless microwave or even a fiber optics transmission, which will add considerably to the total price. If the premises are subject to regular lightning activity, you had better propose fiber optics from the beginning and explain to the customer the savings in the long run. So, you have to find out more about the environment in which the system is going, what is physically possible and what is not, and then plan an adequate video and data transmission media.

• Lastly and probably the most important thing to find out, if possible, is what sort of budget is planned for such a CCTV system?

This question will define and clarify some of the previous queries and will force you to narrow down either the type of equipment, the number of cameras, or how the system is expected to work. Although this is one of the most important factors, it should not force you to downgrade the system to something that you know will not operate satisfactorily.

If the budget cannot allow for the desired system, it is still good to go back to the customer with a system proposal that you are convinced will work as per his or her requirements (even if it is over budget) and another one designed within the budget with as many features as the budget will allow for. This will usually force you to narrow down the number of cameras, or change some from PTZ to fixed.

The strongest argument you should put forward when suggesting your design is that a CCTV system should be a **secure one,** which can only



A mimic keyboard can improve response time considerably.

be the case if it is done properly. Thus, by having a well-designed system, bigger savings will be made in the long run.

By presenting a fair and detailed explanation of how **you think the system should work**, the customer will usually accept the proposal.

Site inspections

After the initial conversation with the customer and assuming you have a reasonably good idea of what is desired, you have to make a site inspection where you would usually collect the following information:

• Cameras: type (i.e., B/W or color, fixed or PTZ, resolution, etc.).

• Lenses: angles of view, zoom magnification ratio for zoom lenses (12.5–75 mm, 8–80 mm, etc.).

• Camera protection: housing type (standard, weatherproof, dome, discrete, etc.), mounting.

• Light: levels, light sources in use (especially when color cameras are to be used), east/west viewing direction. Visualize the sun's position during various days of the year, both summer and winter. This will be very important for overall picture quality.

• Video receiving equipment: location, control room area, physical space, and the console.

• Monitors: resolution, size, position, mounting, and the like.

• Power supply: type, size (always consider more amperes than what are required). Is there a need for an uninterruptable power supply (UPS)? (VA rating in that case).

• If pan/tilt heads are to be used: type, size, load rating, control (two wire – digital or multi-core). Is there a need for preset positioning (**highly recommended** for bigger systems)? Where are they going to be mounted? What type of brackets?

• Make a rough sketch of the area, with the approximate initial suggestions for the camera positions. Take into account, as much as possible, the installer's point of view. A small change in the camera's position, which will not affect the camera's



When making site inspections, you can see the sunlight effects.

performance, can save a lot of time and hassle for the installer and in the end, money for the customer. An unwritten golden rule for a good picture is to try and keep the camera from directly facing light.

• Put down the reference names of areas where the customer wants (or where you have suggested) the cameras to be installed. Also write down the reference names of areas to be monitored because you will need them in your documentation as reference points. Be alert for obvious “no-nos” (in respect to installation), even if the customer wishes something to be done. Sometimes small changes may result in high installation costs or technical difficulties that would be impossible to solve. It is always easier to deter the customer from making changes by explaining why in the initial stage, rather than having to do so later in the course of installation, when additional costs will be unavoidable.

Designing and quoting a CCTV system

With all of the above information, as well as the product knowledge (which **needs constant updating**), you need to sit down and think.

Designing a system, like designing anything new, is a form of art. As is true of many artists, your work may not be rewarded immediately, or it may not be accepted for some reason. But think positively and concentrate as if that is to be the best system you can propose. With a little bit of luck you may make it the best, and tomorrow you can proudly show it to your colleagues and customers.

Different people will use different methods when designing a system. There is, however, an easy and logical beginning.

Always start with a hand drawing of what you think the system should feature. Draw the monitors, cameras, housings, interconnecting cables, power supplies, and so on. While drawing you will see the physical interconnection and component requirements. Then you will not omit any of the little things that can sometimes be forgotten, such as camera brackets, types of cable used, and cable length. Making even a rough hand sketch will bring you to some corrections, improvements, or perhaps further inquiries to the customer. You may, for example, have forgotten to check what the maximum distance for the PTZ control is, or how far the operators are to be from the central video processing equipment, power cable distances, voltage drops, and so on.

Once you have made the final hand drawing, you will know what equipment is required, and it is at this point that you can **make a listing of the proposed equipment**. Then, perhaps, you will come to the stage of matching camera/lens combinations. Make sure that they will fit in the housings or domes you intend to use. This is another chance to glance through the supplier’s specifications booklet. Do not forget to take into account some trivial things that may make installation difficult, like the coaxial cable space behind the camera (remember, it is always good to have at least 50 mm for BNC terminations), the focusing movement of a zoom lens (as mentioned earlier in the chapter on zoom lenses, in a lot of zoom lenses focusing near makes the front optical element protrude for an additional couple of millimeters), and so on.

The next stage is **pricing the equipment** – costs, sales tax and duty, installation costs, profit margins, and the most important of all (especially for the customer) the **total price**.

Do not forget to **include commissioning costs** in there, although a lot of people break that up and show the commissioning figure separately. This is more of a practical matter, since the commissioning cost may vary considerably and it could take longer or shorter than planned. General practical experience shows that it will always take at least three times longer than planned. Also, in the commissioning fees, time should be allocated for the CCTV **operator's training**.

After this step has been completed, you need to make a **final and more accurate drawing** of the system you are proposing. This can be hand drawn, but most CCTV designers these days use computers and CAD programs. It is easier and quicker (once you get used to it), and it looks better.

Also, the hand-calculated price needs to be written in **a quotation form, with a basic explanation of how the system will work and what it will achieve**. It is important for this to be written in a concise and simple, yet precise form, because quotations and proposals (besides being read by security managers and technical people) are also read by nontechnical people such as purchasing officers and accountants. Often, spreadsheet programs are used for the purpose of precise calculation, and this is another chance to double-check the equipment listing with your drawing and make sure nothing has been left out.

As with any quotation, it is more professional to **have a set of brochures enclosed** for the components you are proposing.

In the quotation, you should not forget to include your company's **terms and conditions of sale** which will protect your legal position.

If the quotation is a response to a **tender** invitation, you will most likely need to submit a **statement of compliance**. This is where you confirm whether your equipment complies or does not comply with the tender requirements. This is where you also have to highlight eventual extra benefits and features your equipment offers. In the tender, you may also be asked to commit yourself to the progress of the work and supply work insurance cover, in which case you will need a little bit of help from your accountant and/or legal advisor.



A spreadsheet program can help a lot in preparing a precise CCTV quotation.

Many specialized companies only design and supply CCTV equipment, in which case you will need to get a quote from a specialized installer,

who, understandably, will need to inspect the site. It is a good practice, at the end, to have all the text, drawings, and brochures bound in a single document, in a few copies, so as to be practical and efficient for reviewing and discussions.

Installation considerations

If you are a CCTV system designer, you do not have to worry about how certain cables will be pulled through a ceiling, raisers, or camera pole mounting; that is the installer's job. But it would be very helpful and will save a lot of money, if you have some knowledge in that area. If nothing else, it is a good practice, before you prepare the final quotation, to take your preferred installer on site, so that you can take into account his or her comments and suggestions of how the practical installation should be carried out.

First, the most important thing to consider is the type of cable to be used for video, power, and data transmission, their distances and protection from mechanical damage, electromagnetic radiation, ultraviolet protection, rain, salty air, and the like. For this purpose it is handy to know the surrounding area, especially if you have powerful electrical machinery next door, which consumes a lot of current and could possibly affect the video and control signals.



Strapping a bracket around a concrete column

Powerful electric motors that start and stop often may produce a very strong electromagnetic field and may even affect the phase stability of the mains. This in turn will affect the camera synchronization (if line-locked cameras are used) as well as the monitor's picture display.

For example, there might be a radio antenna installed in the vicinity, whose radiation harmonics may influence the high-frequency signals your CCTV system uses.

Mounting considerations are also important at both the camera and monitor end. If poles are to be installed, not only the height, but also the elasticity of the poles is important. Steel poles, for example, are much more elastic than concrete poles.

If a PTZ camera is installed, the zoom lens magnification factor will also magnify the pole's movement which could result from wind, or vibrations from the pan/tilt head movement itself. This magnification factor is the same as the optical magnification (i.e., **a zoom lens, when fully zoomed in, may magnify a 1 mm movement of the camera due to wind to a 1 m variation at the object plane**).

The shape of the pole is also very important – hexagonal poles are less elastic than round ones of the same height and diameter.

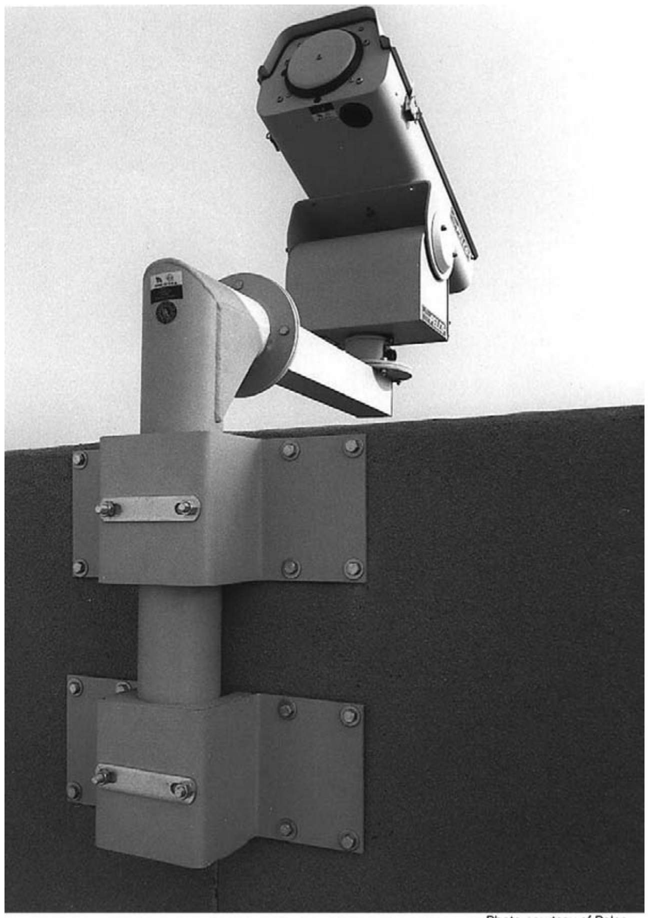


Photo courtesy of Pelco

Pan/tilt swinging bracket

The same logic applies to camera and pan/tilt head mounting brackets. A very cheap bracket of a bad design can cause an unstable and oscillating picture from even the best camera.

If the system needs to be installed in a prestigious hotel or shopping center, the aesthetics are an additional factor to determine the type of brackets and mounting. It is especially important then not to have any cables hanging.

The monitoring end demands attention to all aspects. It needs to be durable (people will be working with the equipment day and night), or aesthetical (it should look good) and practical (easy to see pictures, without getting tired of too much noise and flashing screens).

Since all of the cables used in a system wind up at the monitoring end and in most cases this is the same room where the equipment is located, special attention needs to be paid to cable arrangement and protection.



A hexagonal metal pole is stiffer than a circular pole

Often, cables lying around on the floor for a few days (during the installation) are subject to people walking on them, which is enough weight to damage the cable characteristics, especially the coaxial cable impedance. Remember, the impedance depends on the physical relation between the center core, the insulation, and the shield. If a bigger system is in question, it is always a better idea to propose a raised floor, where all the cables are installed freely below the raised floor.

Sometimes, if a raised floor is not possible, many cables can be run over a false ceiling. In such cases special care should be taken to secure the cables as they could become very heavy when bundled together.

Larger installations may want a patch panel for the video signals. This is usually housed in a 19" rack cabinet, and its purpose is to break the cables with special coax link connectors so as to be able

to reroute them in case of a problem or testing.



Hinged PTZ camera pole makes servicing easier.

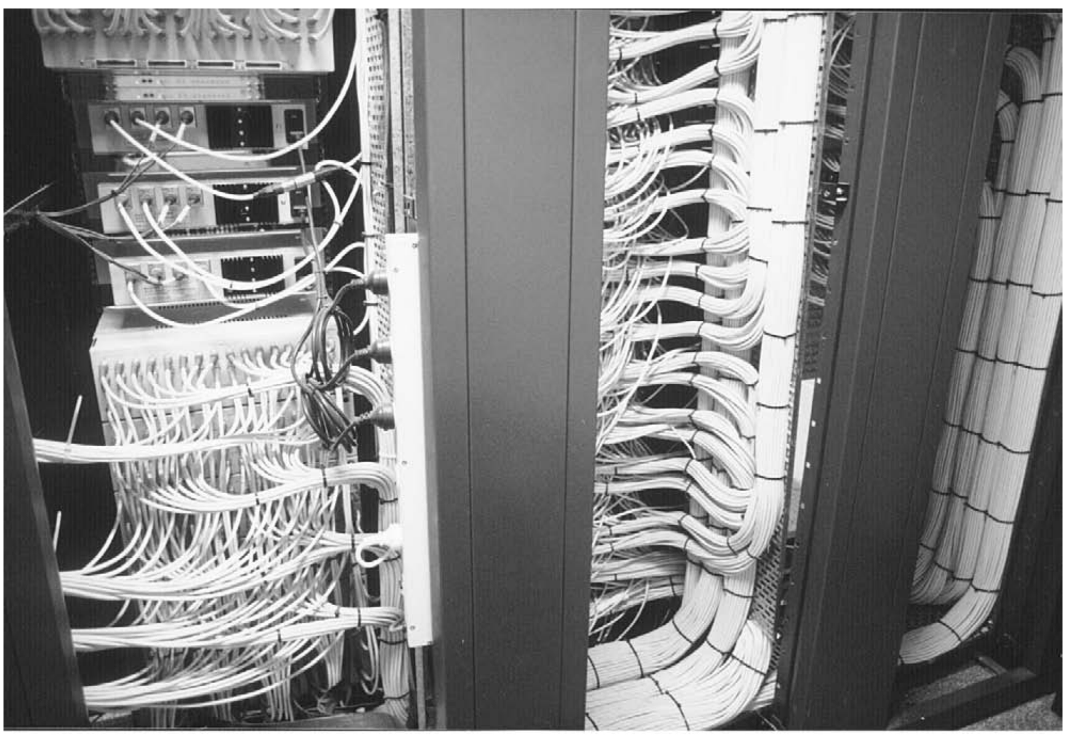
Many installers fail to get into the habit of marking the cables properly. Most of them would know all of the cables at the time of installation, but two days later they can easily forget them. Cable marking is especially critical with larger and more complex systems.

Insist on proper and permanent cable markings as per your drawings. There are plenty of special cable-marking systems on the market. In addition, listing of all the numbers used on the cables should be prepared and added to the system drawings.

Remember, good installers differ from bad ones in the way they terminate, run, arrange, and mark the cables, as well as how they document their work.

Drawings

There is no standard for drawing CCTV system block diagrams, as there is in electronics or architecture. Any clear drawing should be acceptable as long as you have clearly shown the equipment used (i.e., cameras, monitors, VCRs) and their interconnection.



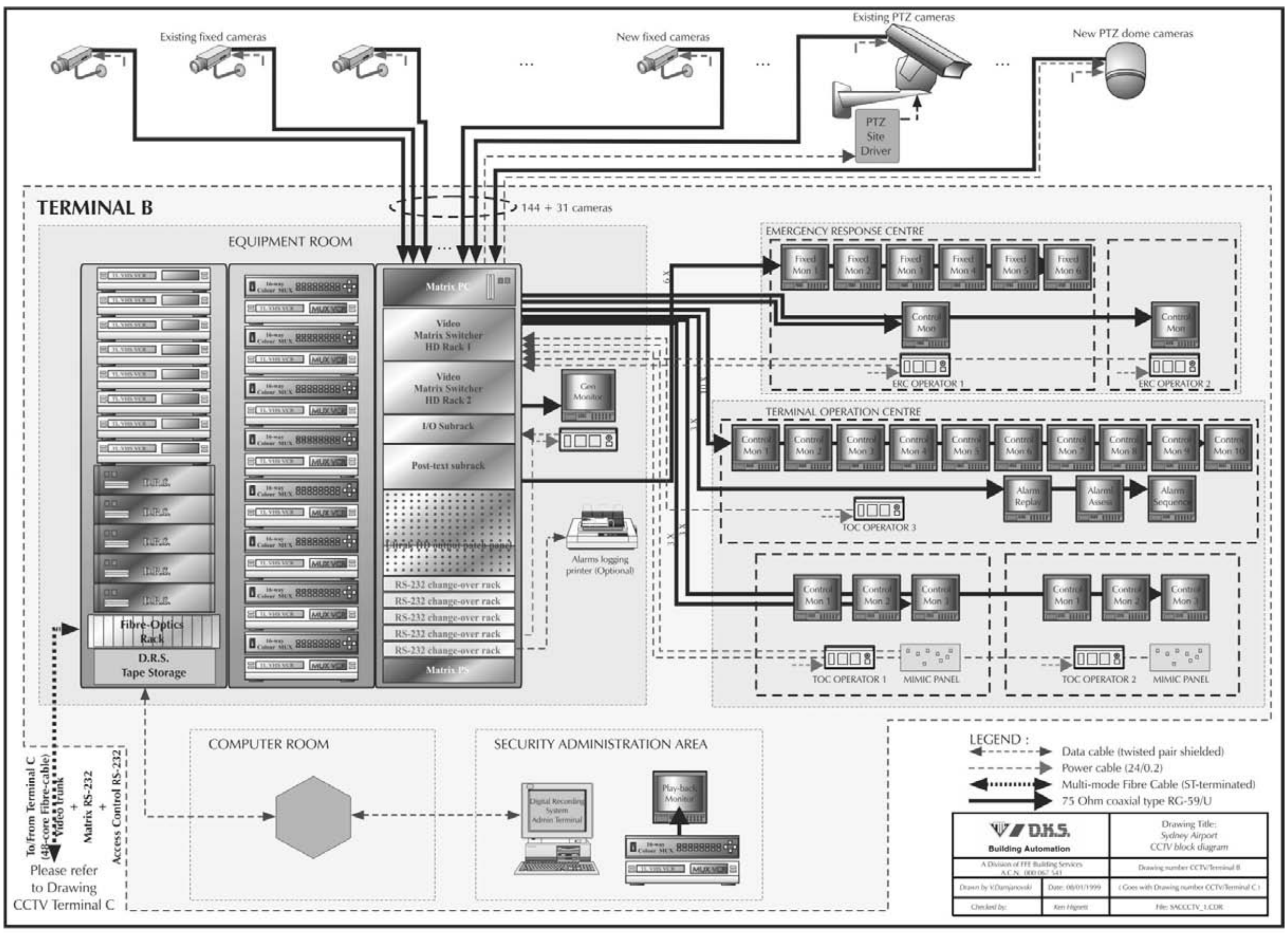
A large cable installation can be a creative challenge.

Many people use technical drawing aids, such as CAD programs, or other PC or Mac-based drawing packages. Depending on the system size, it might be necessary to have two different types of drawings: one of a CCTV block diagram showing the CCTV components' interconnection and cabling requirements, while the other could be a site layout with the camera positions and coverage area. In smaller installations, just a block diagram may be sufficient.

The CCTV block diagram needs to show the system in its completeness, how the components are interconnected, which part goes where, what type of cable is used, and where it is used.

If the site layout drawing is well prepared, it can later be used as a reference by the installer, as well as by your customer and yourself when reviewing camera locations, reference names, and discussing eventual changes.

When the CCTV system is installed and the job is finished, drawings may need small alterations, depending on the changes made during the installation. After the installation, the drawings are usually enclosed with the final documentation, which should also include manuals, brochures, and other relevant documentation.



An example of a CCTV system drawing

Commissioning

Commissioning is the last and most important procedure in a CCTV system design before handing it over to the customer. It involves great knowledge and understanding of both the customer's requirements and the system's possibilities. Quite often, CCTV equipment programming and setup are also part of this. It includes video matrix switcher programming, time-lapse VCR programming, camera setup, and so on.

Commissioning is usually conducted in close cooperation with the customer's system manager and/or operator(s), since a lot of settings and details are made to suit their work environment.

The following is a typical list of what is usually checked when commissioning:

All wiring is correctly terminated.

Supply voltage is correct to all appropriate parts of the system.

Camera type and lens fitted are correct for each position.

Operation of auto irises under various light levels is satisfactory.

If VCRs are fitted, they should be recording in the most efficient time-lapse mode (especially when multiplexed cameras are being recorded).

If DVRs are installed, the pictures per second performance and image quality (compression setting) should be checked .

All system controls are properly functioning (pan/tilt, zoom, focus, etc.)

The setting of all pan and tilt limits is correct.

Preset positioning, if such cameras are used, is correct.

The level of supplementary lighting is satisfactory.

The system must continue to work when the main supply is disconnected, and a check should be made as to how long it does (if UPS is used).



A fully installed system in a 19" racking cabinet

Commissioning larger systems may take a bit longer than the smaller ones. This is an evolution from the system on paper to the real thing, where a lot of small and unplanned things may come up because of new variations in the system concept. Customers, or users, can suggest the way they want things to be done, only when they see the initial system appearance. Commissioning in such cases may therefore take up to a few days.

Training and manuals

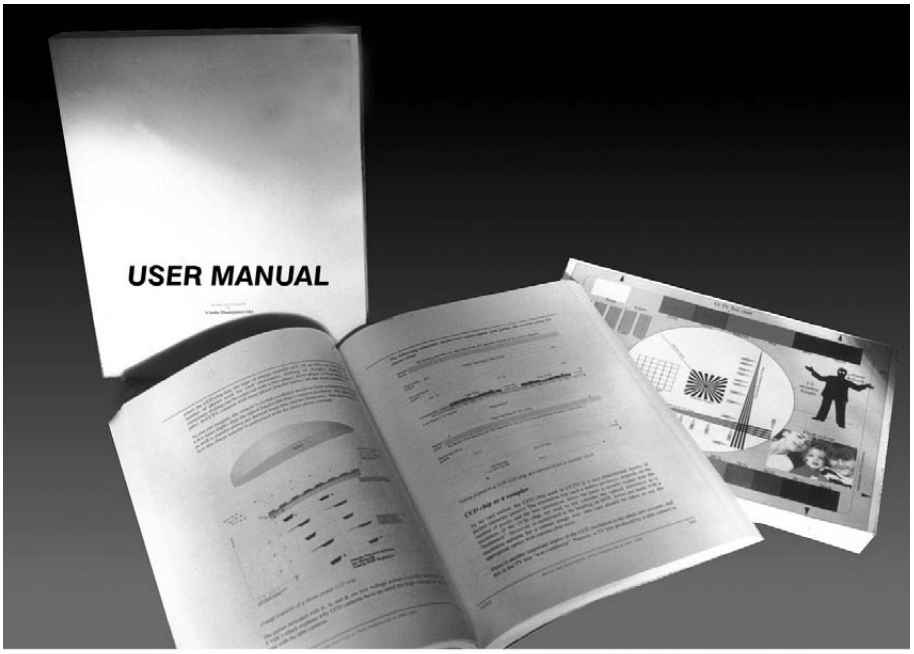
After the initial setup, programming, and commissioning are finished, the operators, or system users, will need some form of training.

For smaller systems this is fairly straightforward and simple. Just a verbal explanation may be sufficient, although every customer deserves a written user's manual. This can be as simple as a laminated sheet of paper with clearly written instructions.

Every piece of equipment should come with its own User's Manual, be it a time lapse VCR, a camera, or a switcher, but they have to be put together in a system with all their interconnections and this is what has to be shown to the customer. Every detail should be covered, especially alarm response and the system's handling in such cases. This is perhaps the most important piece of information to the operators.

For larger systems, it is a good idea to bind all the component manuals, together with the system drawings, wiring details, and operator's instructions, in a separate folder or a binder. Naturally, for systems of a larger size, training can be a more complex task. It may even require some special presentation with slides and drawings so as to cover all the major aspects.

Good systems are recognized not only by their functionality but also by their documentation.



User manuals and equipment documentation are very important to the customer.

Handing over

When all is finished and the customer is comfortable with what he or she is getting, it is time to hand over the system. This is an official acceptance of the system as demonstrated and is usually backed by the signing of appropriate documents.

It is at this point in time that the job can be considered finished and the warranty begins to be effective. From now on, the customer takes over responsibility for the system's integrity and operation.

If customers are happy with the job, they usually write an official note of thanks. This may be used later, together with your other similar letters, as a reference for future customers.

Preventative maintenance

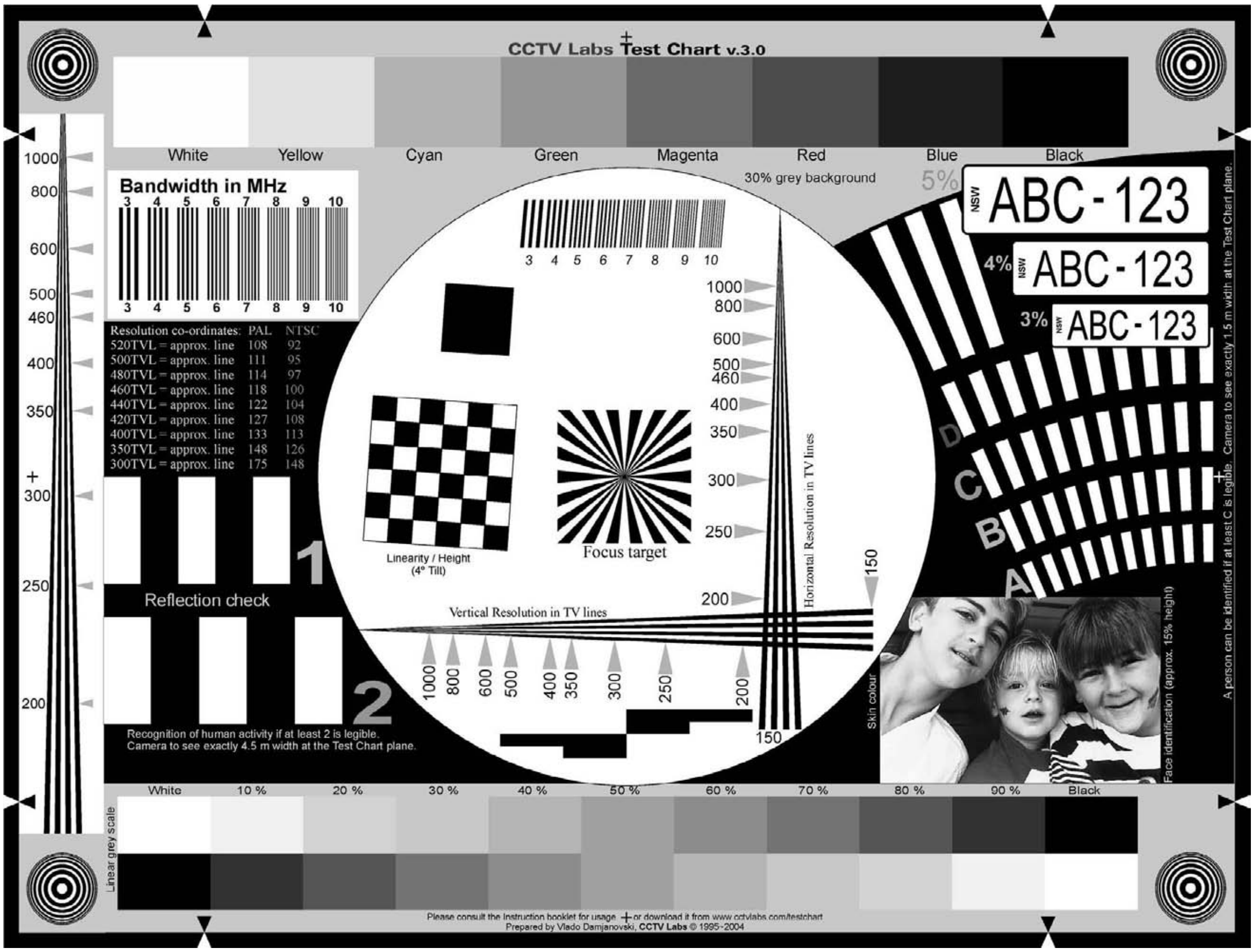
Regardless of the system's use, the equipment gets old and dirty, and faults may develop due to various factors. It is of benefit to the customer if you suggest preventative maintenance of the system after the warranty expires.

This should be conducted by appropriately qualified persons and most often it is the installer that can perform this task successfully. However, a third party can also do this provided the documentation gives sufficient details about the system's construction and interconnection.


Preventative maintenance

The system should be inspected at least twice a year, or in accordance with the manufacturer's recommendations and depending on the environmental aggressiveness. Where applicable, the inspection should be carried out in conjunction with a checklist, or equipment schedule, and should include inspections for loosened or corroded brackets, fixing and cleaning of the housings or domes, monitor screens, VCR heads, DVR air filter, hard disk upgrade, compression versus length of recording correction, improving back-focus on some cameras, and so on.

Larger systems that include intelligent video matrix switchers may require reprogramming of some functions, depending on the customer's suggestions.



Please handle your Test Chart with care.

The CCTV Labs Test Chart was designed primarily for indoor use,

and although it can be used outside,

please avoid direct exposure to water, rain and snow,

as well as long periods of exposure to direct sunlight.

Although the CCTV Labs Test Chart has been designed

specifically for the CCTV Industry,

it can be used to verify the quality of other visual,

transmission and recording systems.

DISCLAIMER: CCTV Labs Pty. Ltd. has designed this chart with the best intentions to offer an objective and independent measurement of various video signal characteristics, and although all the details are as accurate as we can make them, we do not take any responsibility for any damage or loss resulting from the use of the chart.

www.cctvlabs.com

14. Video testing

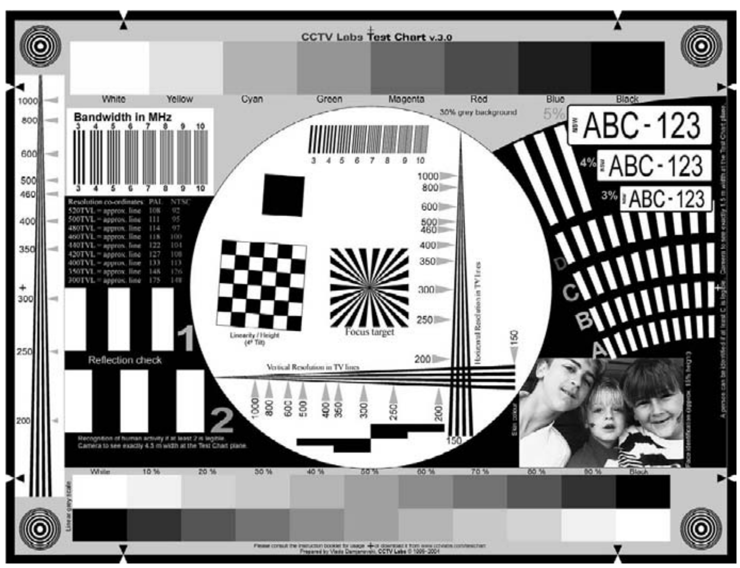
This last chapter will attempt to explain how the CCTV Labs test chart and the CCTV Labs test pattern generator TPG-8 can be used to make certain system evaluation and measurement. These are by no means the only tools on the market. Other test charts and generators are available, but these are specifically developed for the CCTV industry and they are readily available. Furthermore, the test chart is traditionally reproduced on the back cover of this book so it is important for the reader to know how to use it. Just to repeat once again what we said earlier in the book: for more accurate resolution and color measurements we encourage you to obtain the larger A3 format test chart from CCTV Labs web site (***www.cctvlabs.com***).

The CCTV Labs test chart

In order to help you determine your camera resolution, as well as check other video details, CCTV Labs Pty. Ltd. has designed this special test chart in A3 format, a reproduction of which also appears on the back cover of this book.

We have tried to make it as accurate and informative as possible and although it can be used in the broadcast applications, it should not be taken as a substitute for the various broadcast test charts. It should be used for CCTV applications only and as a guide in comparing different equipment and/or transmission media.

This test chart has been updated with some new features compared to the previous edition. This addition refers primarily to the white lines that will allow you to check whether you can recognize a person at a certain distance. This procedure is based on the recommendations of VBG (Verwaltungs-Berufsgenossenschaft): Installationshinweise für Optische Raumüberwachungs-anlagen (ORÜA) SP 9.7/5, and accepted by the European Standards, EN 50132-7, and the Australian CCTV Standards.



With this chart you can check a lot of other details of a video signal, primarily the resolution, but also bandwidth, monitor linearity, gamma, color reproduction, impedance matching, reflection, and digital recorders picture quality at various compression levels.

Before you start testing

Use high-quality lens

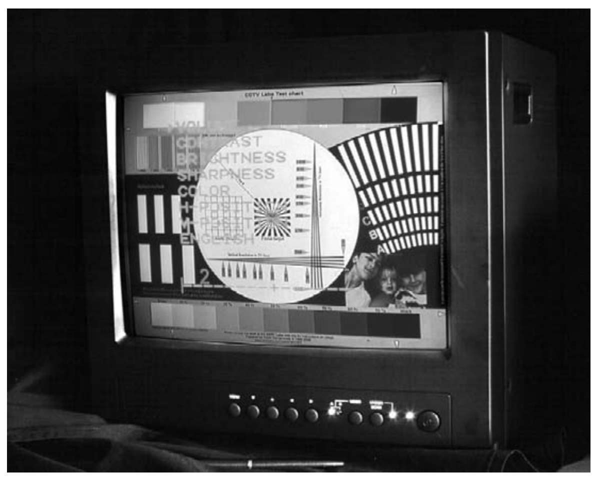
For the best quality picture reproduction of your camera you first have to select a very good lens (that has much better resolution than the CCD chip itself). The smaller the CCD/CMOS chip is (i.e., 1/3" vs 1/4"), the more critical the lens quality is. When the physical chip size (width, for example) is divided by the number of pixels, the number obtained is pixels per millimeter. If we assume, for example, that we have 1/3" CCD chip with 752 horizontal pixels, and knowing the width of 1/3" chip is 4.8 mm, the pixel density will be approximately 6.4 µm, which is equivalent to 156 pixels per mm. In order to have at least this quality lens resolution, we need to have a lens with optical resolution of at least half of this number (i.e., 78 lines/mm). Half of the number is used because in optics when counting lines per millimeter resolution only black lines are counted, as opposed to television where both black and white are. Check the resolution of the lens, expressed in lines/mm, with your lens supplier. Out of all the various lenses (fixed, vari-focal, zoom) the best choice would be a fixed focal-length manual iris lens.



Shorter focal lengths, showing angles of view wider than 30°, should usually be avoided because of the spherical image distortion they may introduce. A good choice for 1/2" CCD cameras would be a 12 mm, 16 mm, or 25 mm lens. For 1/3" CCD cameras, a good choice would be when 8 mm, 12 mm, or 16 mm lens is used.

The longer focal length will force you to position the camera further away from the test chart. For this purpose it is recommended that you get a photographic tripod for the camera.

Use high-quality monitor



Next, you must use a high-resolution monitor with an underscan feature in order to see 100% of what the camera "sees."

Most standard CCTV monitors do not have this feature, but some brands do have it.

When testing camera resolution the best choice would be a high-quality monochrome (B/W) monitor since their resolution reaches 1000 TV lines in the center.

Color monitors are acceptable only if they are of broadcast, or near-broadcast, quality. To qualify for this, a monitor should have at least 500 TV lines of horizontal resolution. Understandably, B/W cameras that have over 500 TV lines of horizontal resolution cannot have their resolution tested with such a monitor, but the majority of color cameras (which have up to 480 TV lines) should be okay for testing with such a monitor.

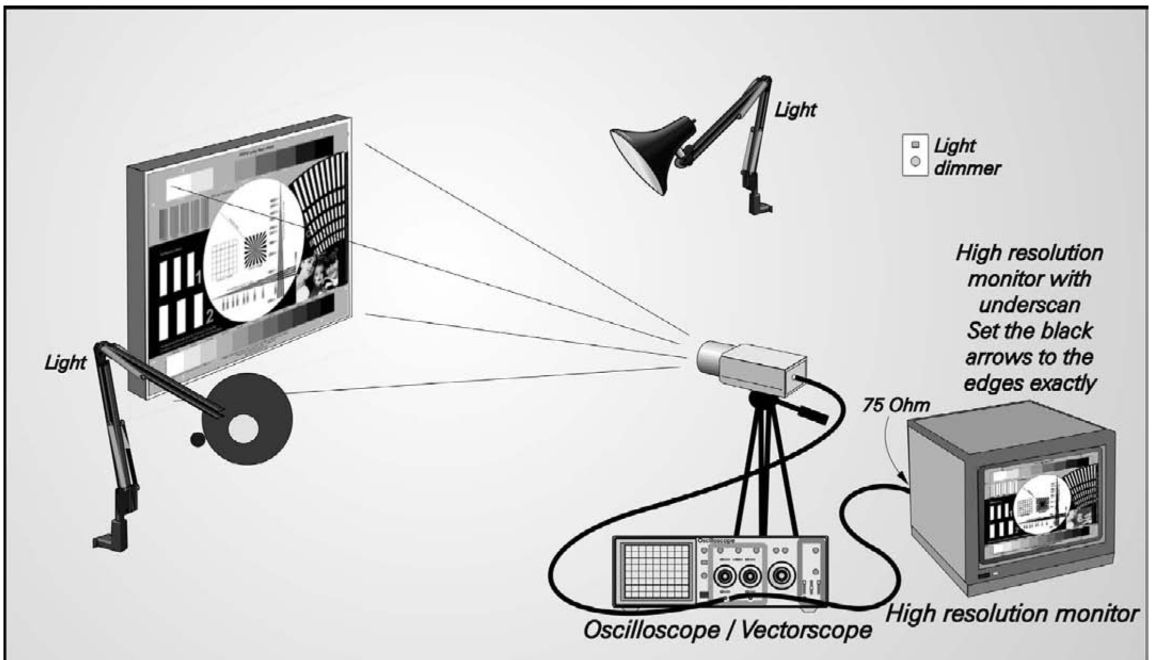
Setup procedure

Position the chart horizontally and perpendicular to the optical axis of the lens (see the accompanying diagram). The camera has to see a full image of the chart exactly to the black/white triangular arrows. To see this you must switch the monitor to the underscan position so you can view 100% of the image.

If you do not have a monitor with an underscanning feature, allow approximately a 10% narrower view of the total chart width (measuring up to the black/white arrows intersection), which might be close to what a normal overscanning monitor would show.

This is, however, not precise for checking resolution. So, if you only have a standard monitor, the following little trick might substitute the more expensive underscanning monitor.

Position the camera with its tripod as closely to displaying the full image as possible. Set the vertical hold on the monitor in such a position to view the vertical blanking sync signal (the horizontal black bar in between TV fields). You should be able to set the V-hold button to such a position as to have a steady horizontal bar somewhere in the middle of the screen. Then, try to adjust the camera with its tripod and/or lens so that you can see both the top and bottom positional triangles on the test chart



Setting up a CCTV chart test bench

touching the edge of the black vertical blanking bar (circled in red). Once you adjust the vertical camera position it is easy to adjust the horizontal so that the test chart picture is in the middle of the monitor screen. Then, and only then, can you read precise data from the test chart.

Illuminate the chart with two diffused lights on both sides, while trying to avoid light reflection off the chart. The test chart surface is a matte finish, which minimizes reflections but still, ideally, the light incident angle should be more than 45º (measured relative to the orthogonal) so that the chart is uniformly illuminated. You can buy a calibrated light source if you want to have a good illumination reference, but as a general rule the following tungsten light globes produce the following color temperatures and lumens:

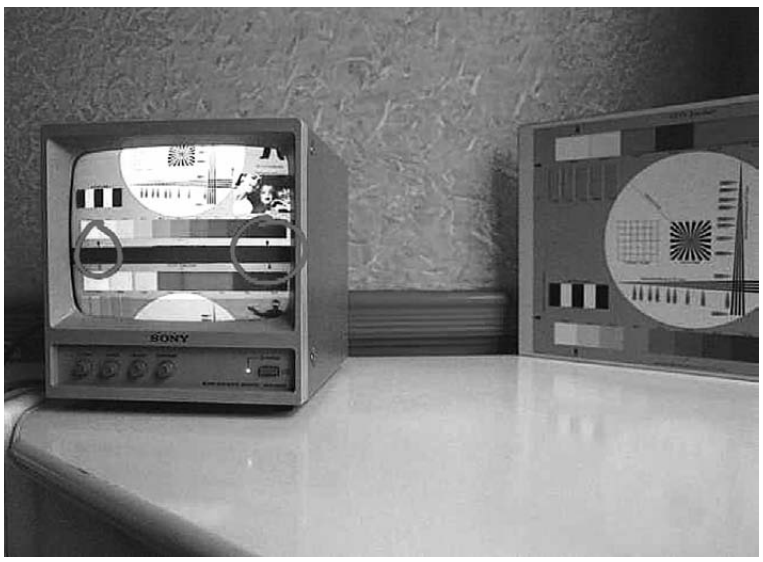
500 W Tungsten => 3200º K (approximately 27 lumens/watt)

200 W Tungsten => 2980º K (approximately 17.5 lumens/watt)

75 W Tungsten => 2820º K (approximately 15.4 lumens/watt)

Ideally, this light source should be reflected from a white metal umbrella type lamp, similar to what photographic studios use for diffusing the light. A uniform light on the test chart is very important for accurate and consistent measurements.

It would be an advantage to have these two lights controlled by a light dimmer because then, you can also test the camera's minimum illumination. Naturally, if this needs to be done, the whole operation will need to be conducted in a room without any external light. Also, if you want to check the low light level performance of your camera, you will need to obtain a precise lux-meter, or perhaps use one of our methods to convert photographic camera EV light reading into luxes (check "***CCTV focus***" issue 9, or download the article from the CCTV Labs web site (***www.cctvlabs.com/testchart***). When using a color camera, please note that the camera needs to be switched on after the lights have been turned on, so that the color white balance circuit detects its white point.



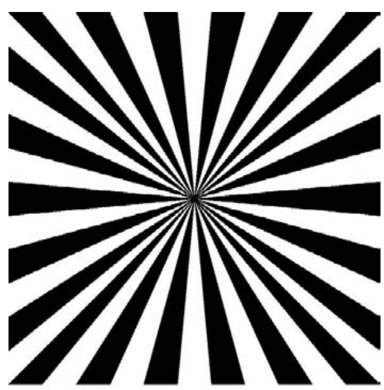
Setting up the test chart without the underscanning monitor

For low light level camera testing a good source of light, and a relatively consistent one, could be a standard candle, at approximately 1 m distance from the test chart. This, by definition, is producing an illumination close to 1 lux on 1 m^2. Because the candle flame cannot always be controlled to the same



Using a candle light at around 1 m from the test chart can be useful in comparing and testing low light camera performance

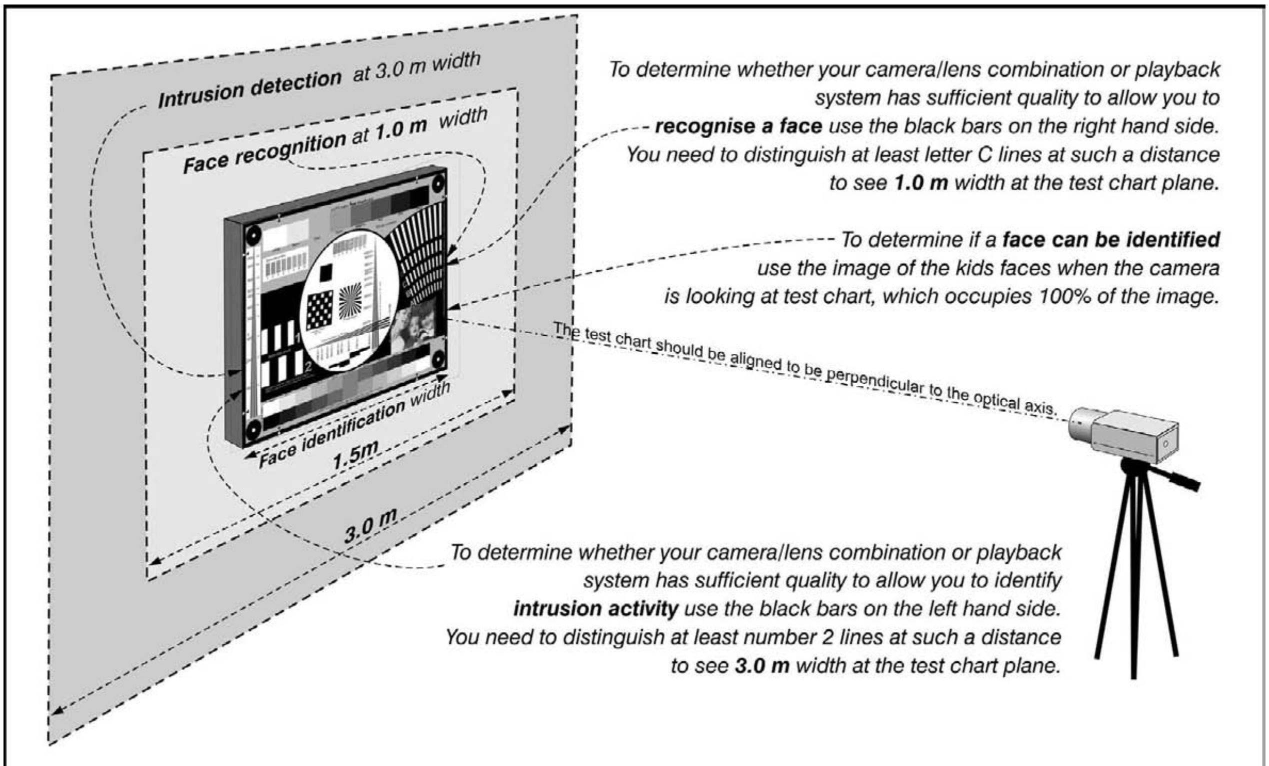
intensity, this illumination is only calculated and should be taken with caution. It should be a sufficiently good reference, however, when comparing the low light performances of various cameras. The candle in such cases should be positioned close to the camera in order to have uniform light at the test chart plane. The best lens used in such a case is a manually controlled zoom lens, so that the camera can be set to have 100% of the test chart in its field of view, while having the candle next to it, not in front (it will affect the video signal level), but also not behind the camera (it will create shadow).



Focus target

Position the camera on a tripod, or a fixed bracket, at a distance that will allow you to see a sharp image of the full test chart. The best focus sharpness can be achieved by seeing the center of the "Focus target" section. Make sure the black/white arrows' tips touch the underscanned picture edge or the black vertical sync bar, if you are using the alternative method described above.

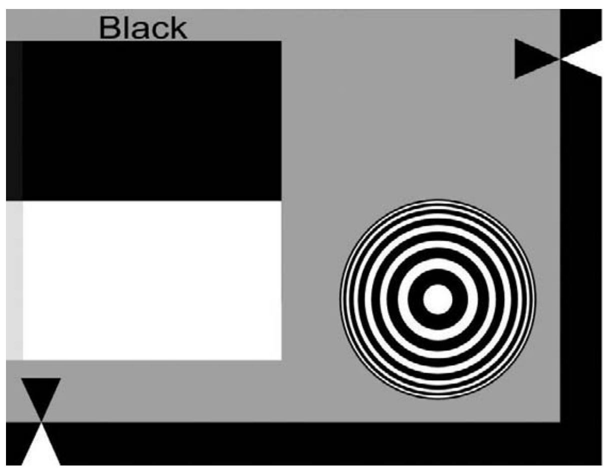
In the latest version of the test chart we have added concentric circles in each of the four corners which can also help you adjust the perpen-



The CCTV Labs test chart setup for face identification, face recognition and intrusion detection

dicular position of the optical axis relative to the test chart plane. Furthermore, these circles can also help you determine whether the CCD chip of the camera has correct 90º positioning relative to the optical axis. Some cameras with lower quality back-focus mechanisms have obvious misalignment of the CCD chip plane, which can be determined by looking at the concentric circles. In order to obtain minimum depth of field, open the iris fully for such measurement.

For optimum test chart sharpness set the lens's iris to the middle position (F-5.6 or F-8), which is the best optical resolution in most lenses, and then adjust the light dimmer to get a full dynamic range video signal. In order to see this, an oscilloscope will be necessary.

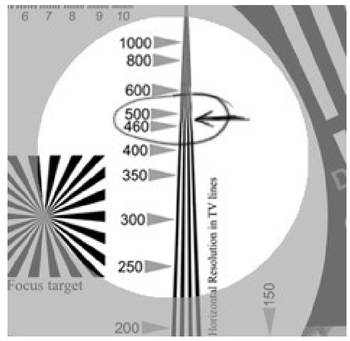


Do not forget to switch off all the video processing circuits in the camera you are testing (i.e., AGC, CCD-iris, BLC).

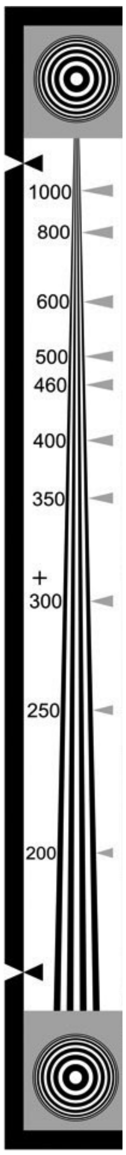
Make sure that all the impedances are matched, that the camera sees 75 ohms at the end of the coaxial line.

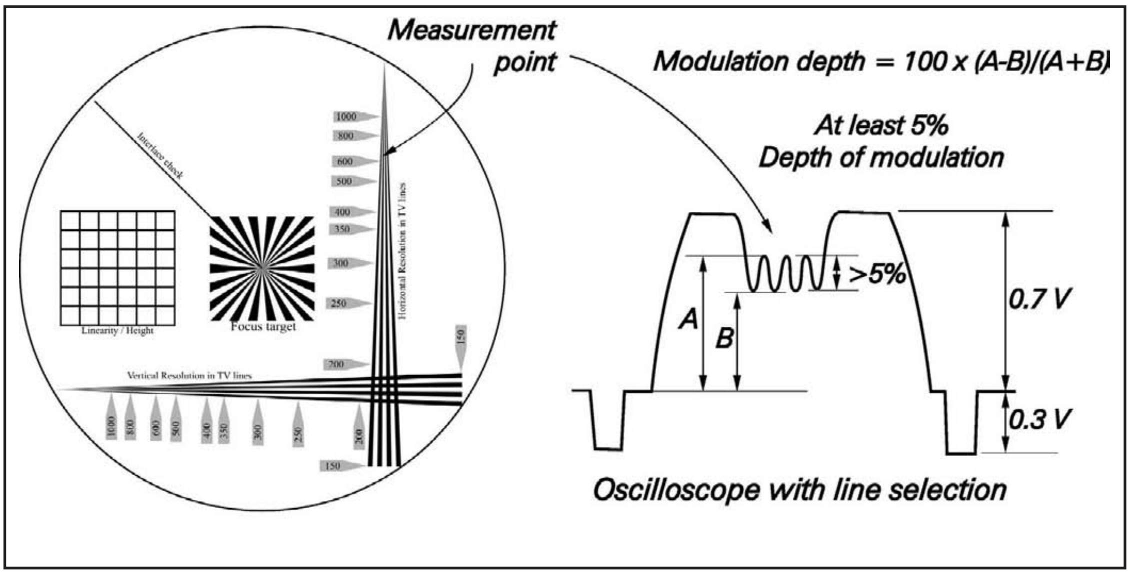
What you can test

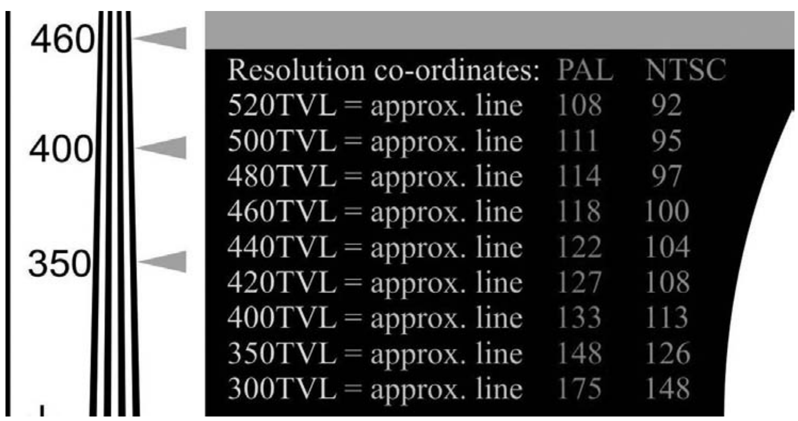
Resolution



To check the camera ***resolution*** (either vertical or horizontal), you have to determine the point at which the four sharp triangular lines inside the circle converge into three. That is the point where the resolution limits can be read off the chart. The example on the right shows a horizontal resolution of approximately 550 TV lines. For a more precise reading of the horizontal resolution, as per the broadcast definition, you would need an oscilloscope with a line selection feature. The resolution limit is then determined with the oscilloscope rather than relying on the visual performance of your monitor. By definition, resolution limit is where the depth of modulation is around 5%. In order to use these, we have redesigned the test chart to make easier and more accurate measurements with line selection oscilloscopes.







Resolution co-ordinates:	PAL	NTSC
520TVL = approx. line	108	92
500TVL = approx. line	111	95
480TVL = approx. line	114	97
460TVL = approx. line	118	100
440TVL = approx. line	122	104
420TVL = approx. line	127	108
400TVL = approx. line	133	113
350TVL = approx. line	148	126
300TVL = approx. line	175	148

Coordinates of TV lines for 5% depth of modulation

Position the camera on a tripod, or a fixed bracket, at a distance that will allow you to see a sharp image of the full test chart. The best focus sharpness can be achieved by see-

ing the center of the “Focus target” section. Make sure the black/white arrows’ tips touch the underscanned picture edge or the black vertical sync bar, if you are using the alternative method described above.



An actual photo of a camera showing around 460 TVL resolution

If the alignment with white/black arrows is precise, then the line counting starts from the top of the monitor, having 288 active lines in a PAL TV field and 240 in NTSC TV field.

In order to verify (or measure) horizontal resolution of, for example, 400 TVL, the line counted as number 133 in PAL TV signal should show around 5% depth of modulation. For NTSC this measurement should be around line 113. In order to see and more easily locate the depth of modulation, the horizontal resolution measurement lines have been replicated at the very beginning of the test chart, so that they can be selected easily and the TV line trigger locked when using oscilloscope.

Please make note that these are approximate line coordinates; errors will depend on the precision of your test chart/camera alignment, as well as the calibration and accuracy of your oscilloscope display.

Vertical resolution in cameras is seldom debated because it is limited by the scanning lines of the PAL or NTSC system, but the horizontally positioned four lines that reduce in thickness are sufficient to measure it.

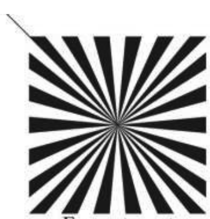
Other important measurements

If you want to check the video ***bandwidth*** of the signal, read the megahertz number next to the finest group of lines where black and white lines are distinguishable.



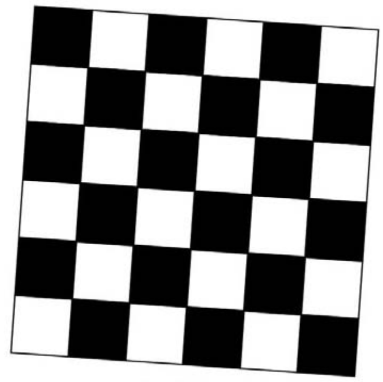
The tilted bandwidth lines (tilted at 4º exactly relative to the horizontal axis) inside the large circle will help you determine artifacts produced by various CCD chip pixels, which depends on the pixel size, alignment, and color mosaic.

The small concentric lines in the center square of the test chart can be used for easy ***focusing*** and/or ***back-focus adjustments***. Prior to doing this, you should check the exact distance between the camera and the test chart. In most cases, the distance should be measured to the plane where the CCD chip resides. Some lenses, however, may have the indicator of the distance referring to the front part of the lens.


Focus target

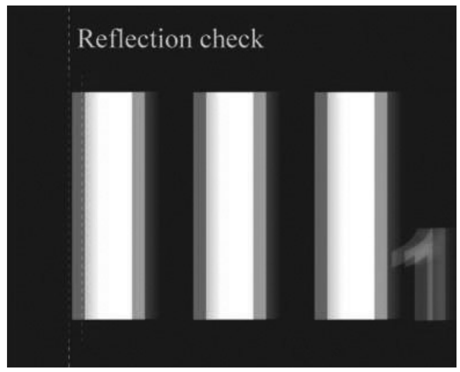
The large circle reproduction will show you the linearity of your monitor, since

CCD cameras have no geometrical distortion by design. Sometimes linearity can be more easily checked by measuring the vertical and horizontal length of the 6 × 6 squares, left of the focus square. These squares are tilted exactly 4º in order to show you different artifacts from pixel size and geometry.

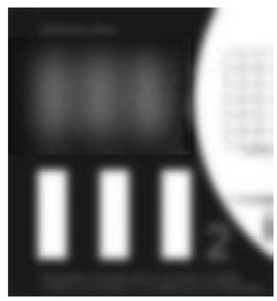


Linearity / Height
(4° Tilt)

The wide black and white bars on the left-hand side have a twofold function. First, they will show you if your impedances are matched properly or if you have ***signal reflection***, that is, if you have a spillage of the white into the black area (and the other way around), which is a sign of reflections from the end of the line. The same can be used to test long cable run quality, VCR playback, and other transmission or reproduction media.



Second, you can determine whether your camera/lens combination gives sufficient details to ***recognize human activity***, such as intrusion or holdup. For this reason you must position the camera at such a distance to see 4.5 m width at the test chart plane. If you can distinguish the bars, then your camera/lens combination is good for recognizing activity. Obviously, reading bars at number 1 is better than at number 2. Use one of the formulas described under the focal length section to find out the distance you have to go to with the lens you have.



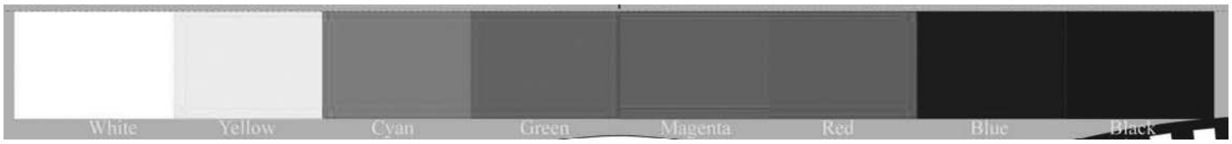
The white tilted bars on the right-hand side have a similar purpose as the thicker ones on the left-hand side. If you recognize the lines near the green letter C, or even better B and A when the camera is at a distance to see 1.5 m width at the chart, then you can ***identify a person*** at such a distance. A is better than B, which is better than C. Again, to find out at what distance you need to position the camera so as to see 1.5 meter width, use the same formula mentioned earlier. This test can be very useful to find out if your camera/lens combination gives sufficient details. Such measurement is even more informative in determining the playback quality of a digital video recorder since there is no objective method of determining compression/decompression quality in CCTV.



Another measurement that can be done with the image of children's faces is the ***face recognition***, as defined by the CCTV standards, where it is required that a person occupy 100% of the picture height, in which case the face occupies around 15% of the test chart height. The face sizes are made to fulfill these requirements.

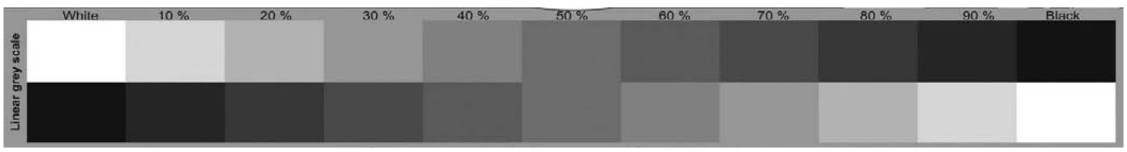
The ***color*** of the flash skin of the three kids will also give you a good indication of your system's reproduction of Caucasian human flesh color. In such a case you must take into account the color temperature of your light source.

For an even more accurate ***color test*** of your camera, use the color scale on the top of the chart, which are printed colors matching the color bars produced by a typical broadcast test generator. If you have a vectorscope, you can check the color output on one of the lines scanning the color bar. As with any color reproduction system, the color temperature of the source is very important and in most cases it should be a daylight source. Most ATW (Automatic Tracking White) color cameras should be able to compensate for various temperature light sources. This means that by switching the light between natural and artificial and following how the color reproduction adjusts indirectly, the ATW capability of the camera can be tested.



The colors are chosen in accordance with the broadcast television standards, in standard order starting from the lightest – white, yellow, cyan, green, magenta, red, blue, and black. Using a vectorscope, you can check accurate color reproduction and white balance on a camera.

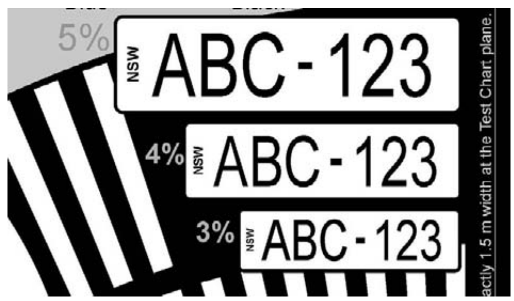
The gray background is set to be exactly 30% gray, which, together with the gray scale at the bottom, can be used to check the ***gamma*** setting of the camera/monitor.



This gray scale is a linear one, as opposed to some logarithmic scales you may find. A linear scale is chosen because the majority of today's cameras are with linear response, which makes it easy to adjust various levels on an oscilloscope.

The gray scale can also be used to set up the *optimum contrast/brightness of a monitor*. The purpose is to set up brightness and contrast in such a way so as to be able to see all levels of gray. Typically, lower contrast is better as it gives richer gray scale details and also produces sharper images (the electron beam is thinner). More importantly, monitor phosphor will last much longer when the settings are made this way. Very often, in order to have optimum monitor settings, external light sources have to be minimized. Always make an effort not to position a monitor screen facing a bright window.

Finally, we have three different sizes of license plates in the top right-hand corner. The 5% is the minimum requirement, as per CCTV standards, where the characters represent 5% of the test chart height. If you can clearly read this license plate after it has gone through your system, perhaps being recorded and played back, that means your system is compliant with the standards. If you manage to get clear reading of the 4%, or, better still, the 3%, your system has even better license plate reading capability. Understandably, the camera has to be positioned so that it sees 100% of the test chart.



Getting the best possible picture

To have the best possible picture setting on a monitor follow these steps:

- Set the camera to 1 V_{PP} video signal, while viewing the full image of the test chart.
- Set the monitor contrast pot in the middle position.
- Set the brightness pot to see all steps of the gray scale.
- While doing the above, readjust the contrast pot if necessary.
- Observe and note the light conditions in the room while setting this up, for this dictates the contrast/brightness setting combination.
- Always use a minimum amount of light in the monitor room so that you can set the monitor brightness pot at the lowest position. When this is the case, the sharpness of the electron beam of the monitor's CRT is maximum since it uses less electrons. The monitor picture is then not only sharper, but the lifetime expectancy of the phosphor will be prolonged.

Lately, there have been an increasing number of LCD monitors with composite video inputs. Please be aware of the re-sampling such monitors perform in order to fill up a composite analog video into a (typically) XGA screen (1024 × 768 pixels). Because of this, LCD monitors are not recommended for resolution testing.



If image testing needs to be done using a frame grabber board on a PC, use the highest possible resolution you can find, but not less than the full ITU-601 recommendation (720 × 576 for PAL, and 720 × 480 for NTSC). Again, in such a case, native camera resolution testing cannot be performed accurately as signal is digitized by the frame grabber. If however, various digital video recorders are to be compared, then the "artificial (digitized) resolution" can be checked and compared.

And last, but not least, when light illumination is measured, the CCTV Labs test chart has approximately 60% reflectivity. For more accurate lux measuring use industrial light meters with lux scale, such as Gossen or Minolta models. If this is not available, please refer to Chapter 2 for instructions on how to use a photographic camera to read luxes.

For the latest updates and instructions on various measurements, please visit the CCTV Labs web site regularly at ***www.cctvlabs.com/TestChart/testchart.html***.

Measurement of the digital image compression quality

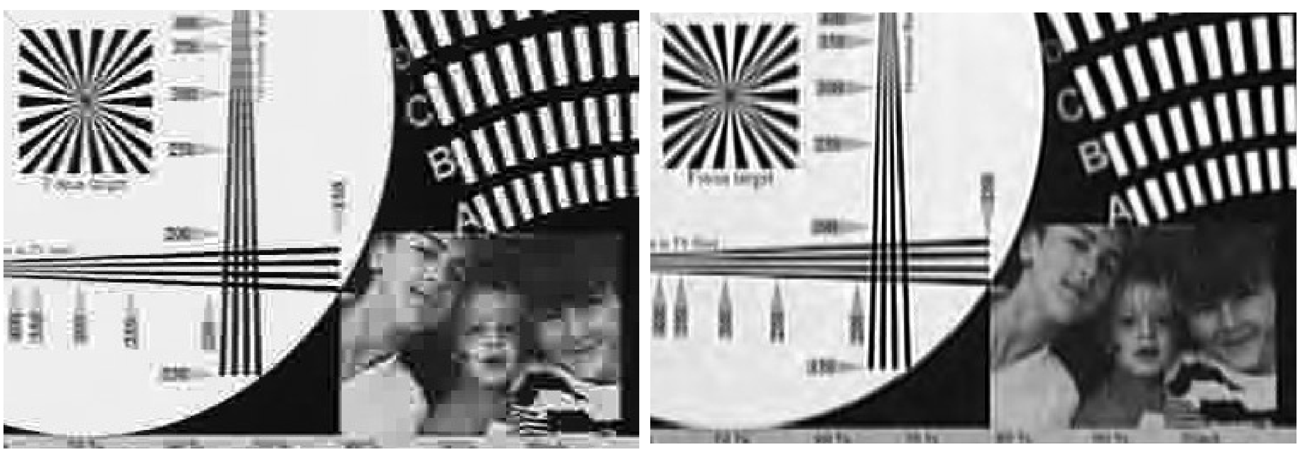
The CCTV Labs test chart can also be used to determine and compare the quality of various digital compression techniques, regardless of the type. For an objective measurement and comparisons, all you need to do is to be able to export a still noncompressed image from the digital recorder (usually bitmap – BMP).

To do this, set up a camera to see 100% of the test chart (use the underscanning monitor). Adjust the camera and lens parameters to produce the best quality picture (1 V_{PP} video signal, focus adjusted on the "Focus target," lens iris at the middle setting).

Record the video signal on the (digital) recording equipment and then play it back and export a selected image of the full test chart. When exporting, select BMP format for maximum picture quality. BMP does not compress, in addition to the compression used in the recorder. Copy the file(s) onto a PC and open them with Photo Editing software (Photo Shop, Photo Paint, and alike). Open all the images that you want to compare and select full screen display. Switch between various compressions and images using "Ctrl-Tab" for easiest comparison.

Various compression schemes have various compression artifacts. JPG, for example, produces blockiness in 8 × 8 pixels block sizes, while Wavelet smears the low detail areas, as shown in Chapter 9. The children's faces in the test chart is the area where compression quality can be determined easily. Other parts of the chart, however, will give you other valuable details about a certain picture quality, resulting from the recording/compression quality. This can only be learned by experimenting.

For more BMP examples visit: ***http://www.cctvlabs.com/TestChart/testchart.html***.



JPG (on the left) and Wavelet (on the right) exports

The CCTV Labs test pattern generator TPG-8



The CCTV Labs programmable test pattern generator TPG-8 is a helpful tool in a variety of cases in closed circuit and broadcast television where certain properties and qualities of video signal have to be determined.

Because the TPG-8 is fully programmable (any existing or custom made test patterns can be inserted), there is no limit to what can be checked.

The following details, however, are the most common video signal properties that could be analyzed:

1. Video signal bandwidth (MHz).

2. Linearity, gamma, and age of monitors.

3. Optimizing the contrast and brightness of a video monitor display.

4. Digital video recording, playback, and export image quality.

5. Minimum or maximum video signal levels acceptable by a device.

6. Transmission link (device) quality.

7. Ground loop problems.

8. Image distortion after digitization of images.

9. Video signal dynamic range.

10. Video signal impedance matching or line end signal reflection.

11. VCR playback quality.

12. Face identification and recognition capability of a recorder (DVR).

13. Vehicle license plate recognition capability of a recording system.

There are many more custom-designed test patterns that can be created to suit your specific needs. CCTV Labs encourages development and exchange of such designed test patterns among users. We will endeavor to include the most interesting on our web site ***www.cctvlabs.com*** for free download.

How you could use the TPG-8

In a typical CCTV system installation, if the signal displayed on a monitor is bad, any part of the video signal path can be "blamed" for it.

Some of the factors that could be the reason for a problem in a CCTV system are:

- The camera itself
- Bad lens setting
- Incorrect back-focus
- Bad cable termination
- Ground loop
- Excessive cable length
- External electromagnetic interferences
- Incorrect amplifier settings
- Bad quality (compression) recording device
- Low-resolution recording device
- Bad monitor, or bad monitor settings, and so on.

This listing makes it quite understandable that for many installers, technicians, or engineers, it is almost impossible to rectify a problem since the method of elimination could be too costly or time consuming.

This is where the CCTV Labs TPG-8 is an irreplaceable tool.

By inserting the TPG-8 at the camera end, a number of possible problem sources are automatically eliminated: the camera, the lens, the lens setting, and the possible ground loop. This is because the TPG-8 is a portable device, always generating constant and precise video levels, and since it is powered from internal batteries, no ground loops can be created.

Once a test image from the TPG-8 has been inserted at the camera end, the result can be observed, recorded, analyzed, and compared. Simply insert the same signal pattern, or better still, use another TPG-8 at the receiving end so that the image qualities can be compared.

Knowing that the TPG-8 always sends the same high-quality video signal, exactly 1 V_{PP} as defined by PAL or NTSC analog video standards, it can easily be read and compared.

The best part of the CCTV Labs TPG-8 is that these patterns are fully programmable and customizable.

This means that you are not limited to the eight patterns that came with your TPG-8, but you can create your own, or download new ones, from the CCTV Labs web site (***www.cctvlabs.com***).

Better still, you can customize any pattern and insert your own logo or company name in it. This is an extremely sophisticated advertising for your company, be that a manufacturer, distributor, consulting, or installation business.

The TPG-8 comes with the TPG Navigator program on a CD, and all that is required is a standard PC with USB connectivity. This program can be used to read your eight current patterns loaded into the TPG-8 memory as well as allow you to write any pattern you want to replace.

There are eight pattern cells, each with sufficient memory allocated to accept a standard resolution digital signal as defined by the ITU-601 standard (i.e., 720 × 576 pixels), at 24-bit colors (RGB, 16 millions). These cells can be overwritten with new patterns whenever you want and as per your choice.

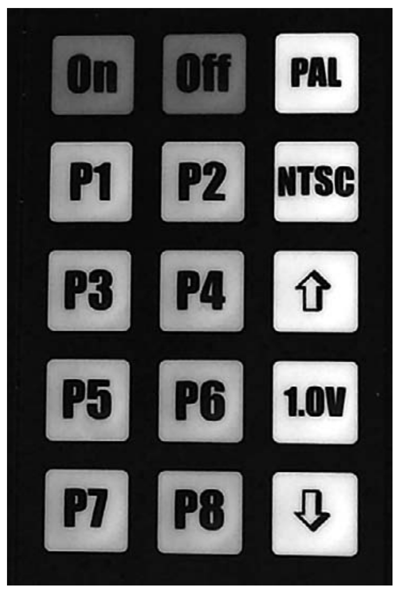
The simple procedure of creating a new test pattern is explained further in this manual, and if you are capable of copying your digital images from your digital camera back to your PC, you should have no problems doing so with the TPG-8 as well.

TPG-8 buttons description

The CCTV Labs test pattern generator TPG-8 generator is turned on by pressing the **On** button and turned off by pressing the **Off** button.

When the power is on, the front panel green LED is on.

Press buttons **P1, P2,** ... **P8** to switch between the corresponding images stored in the flash-memory of the generator.



These numbers correspond to the numbers shown in the TPG Navigator, as illustrated further in this manual.

Select your video standard (PAL or NTSC) by pressing the **PAL** or **NTSC** button.

The TPG-8 remembers the last buttons you have pressed, so there is no need to re-select the video standard or the last pattern you have used.

You can increase or decrease the video output signal level by pressing the arrows ↑ and ↓. The video level increase or decrease is done in small steps in tens of millivolts and has to be done by repetitive presses. Holding the arrow buttons will not continue to increase or decrease the video level.

The minimum level, when the TPG-8 is terminated with 75 Ω , will go down to 300 mV_{pp} and maximum to 1.5 V_{PP} . Such extreme levels can be used to verify certain minimum sensitivity or saturation voltage of various devices (DVRs, monitors) or transmission sets (fiber optics, twisted pair, or RF transmitters). Should you be using this feature, do not forget to reset the output level to the nominal value of 1 V_{PP} .

The default video signal level of 1.0 V is set by pressing the button **1.0 V**.

Connections

The accompanying photos represent the following video output sockets of the generator (left to right):



- Composite (monochrome) video signal (CVS);
- Composite video burst signal output (CVBS);
- S-Video (Y/C) output.

Typical and most common usage is with the CVBS output.

The following connections are mounted at the bottom:



- External 5 VDC power supply socket;
- USB cable socket.

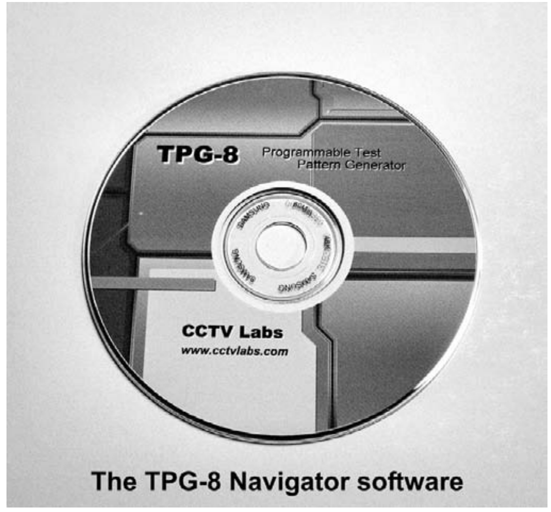
In addition, there is a yellow LED next to the USB socket which flashes when data between a PC and the TPG-8 is exchanged.

The TPG-8 Navigator software

The TPG-8 Navigator is program supplied on the CD together with the generator. This is the software you require in order to load a different pattern, should you decide to make your own or to use any of the patterns available from the CCTV Labs web site. This software is designed to run on Windows 98, 2000, or XP machine with USB interface.

The TPG Navigator has the following buttons (selections) and settings:

- **Preview all images,** shows all images in the TPG-8, in a split-screen mode (when connected with USB cable).
- **Display** shows a selected image in small screen. This is quicker than Preview and useful



The TPG-8 Navigator software

when you know which pattern (button) you are previewing.

• **Read** shows a selected image in larger screen. It takes longer to load but shows better pattern details.

• **Write** an image, as the name suggests, writes a pattern image into the TPG-8. If the image is readable and acceptable by the TPG-8, it will be shown in preview mode.

When an image is written into the TPG-8, it overwrites the previous image loaded in the memory cell, of which the button was pressed (Pict.1 to Pict.8).

Before the pattern is written into the TPG-8, the software shows an image of the selected file and asks if this needs to be written as PAL or NTSC (also selectable under the System setting).

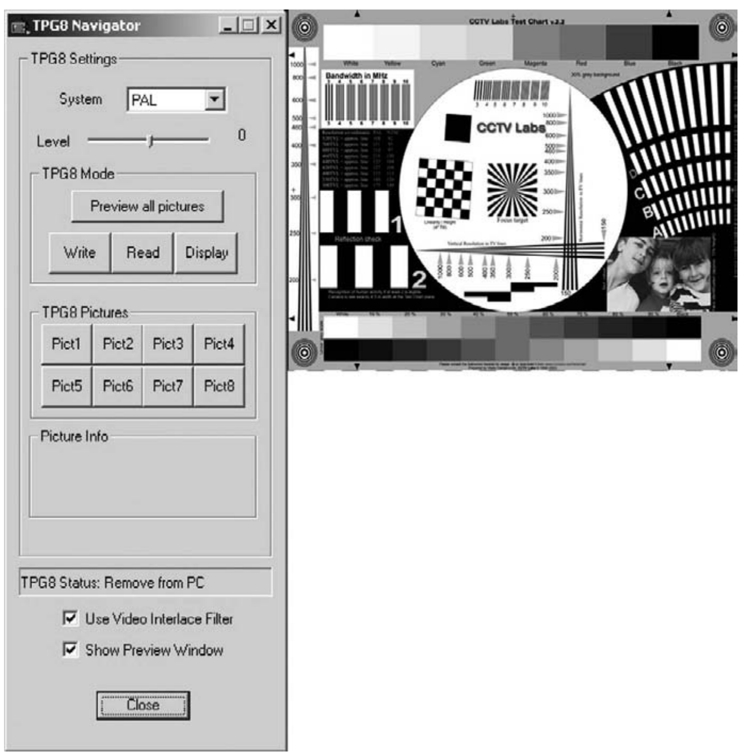
The **Level** setting defines the video level that the TPG-8 produces and typically should be left to the middle setting of 128.

Use the **Video Interlace** filter for smoother video output.

Show Preview window needs to be ticked if you want to see a preview of the images.

Instruments used with the TPG-8

Ideally, and for most accurate video measurements, an oscilloscope and a vectorscope should be used with the TPG-8. In order to be able to see and compare various aspects and details of the variety of patterns, an oscilloscope with line selection capability should be used. In order to compare color reproduction a vectorscope is recommended.



Test patterns and how to create them

The video output level produced by the TPG-8 is typically $1V_{pp}$, when terminated with 75 Ω. The actual video signal is recreated from a digital pattern as per the ITU-601 recommendation (i.e., with 720 × 576 pixels for PAL and 720 × 480 for NTSC). These are the resolution limits for analogue TV, and there is no sense (although technically possible) in having any higher resolution than these.

A technically minded user will notice that none of the above pixel counts has an aspect ratio of 4:3 as is the actual Standard Definition monitor screen ratio. In PAL, for example, there are 576 active scanning lines and to get the same aspect ratio of 4:3 (assuming square picture elements) we would require 768 horizontal elements (pixels). For the same reason, in NTSC, where there are 480 scanning lines, we would require 640 horizontal pixels in order to get 4:3. This is where the ITU-601 standard has actually found "common ground" of 720 horizontal pixels for both PAL and NTSC. In order to get the appropriate aspect ratio for PAL, the signal is "stretched" horizontally a little bit, whereas in NTSC they are "compressed" horizontally, so that a 4:3 aspect ratio is obtained. These manipulations are done by high-precision 10-bits D/A output engine of the TPG-8, so that maximum quality is achieved.

This is a normal procedure in all digital video sources, and for this reason it should be explained clearly that the resolution of the pattern created in any photo editing program (Photoshop, Photo paint, Paintshop Pro, etc.) can be either 720 × 576 or 768 × 576. In the latter case, the TPG Navigator converts the pixel count to be 720 × 576, if working within PAL. Similar logic applies if working in NTSC.

Larger pattern sizes of twice, three times, or four times the original is possible (1440 × 1152 for example), and in fact is recommended for better quality, as the TPG uses high-quality Mitchell filtering to re-sample such a bitmap to the required 720 × 576.

The best file formats to use are the noncompressed TIF or BMP.

When using TIF files, care should be taken not to select LZW lossless compression under the saving options.

JPG is also accepted by the TPG, but low compression ratios (less than 10×) should be used in order to minimize compression artifacts.

In all cases, the color space used in the photo application should be RGB only, 8 bits per color. Care should be taken not to use any other color space, such as CMYK, in order to have accurate color reproduction.

All patterns supplied with the TPG-8 are also available from the CCTV Labs web site, and new ones will be added as they become available. Please visit ***www.cctvlabs.com*** for updates.

CCTV Labs *reserves the rights to change specifications for further product improvements.*

Specifications

Dual analog TV standard – **PAL, NTSC**.

Video signal is compliant with recommendations of ITU-R BT.470-4 “Television Systems” (former CCIR Report 624).

Video signal analog output: **S-Video, Composite**.

Possibility to vary the TPG signal voltage in the range: **0.3 V_{PP}–1.5 V_{PP}**.

Default level **1.0 V_{PP}**, when terminated with 75 Ω.

Test pattern loading via **USB**.

Maximum test images recorded in the generator **8**.

Power:

- Built-in 3 × 1.5 V rechargeable batteries;
- External 5 VDC power supply;
- USB PC port power.

Charging the built-in batteries and generator power supply through the mains adapter:

- Source output voltage 5 ± 0.2 V.
- Power consumption minimum 5 W.

Autonomous power supply of the generator is through 3 NiMH batteries, AA type.

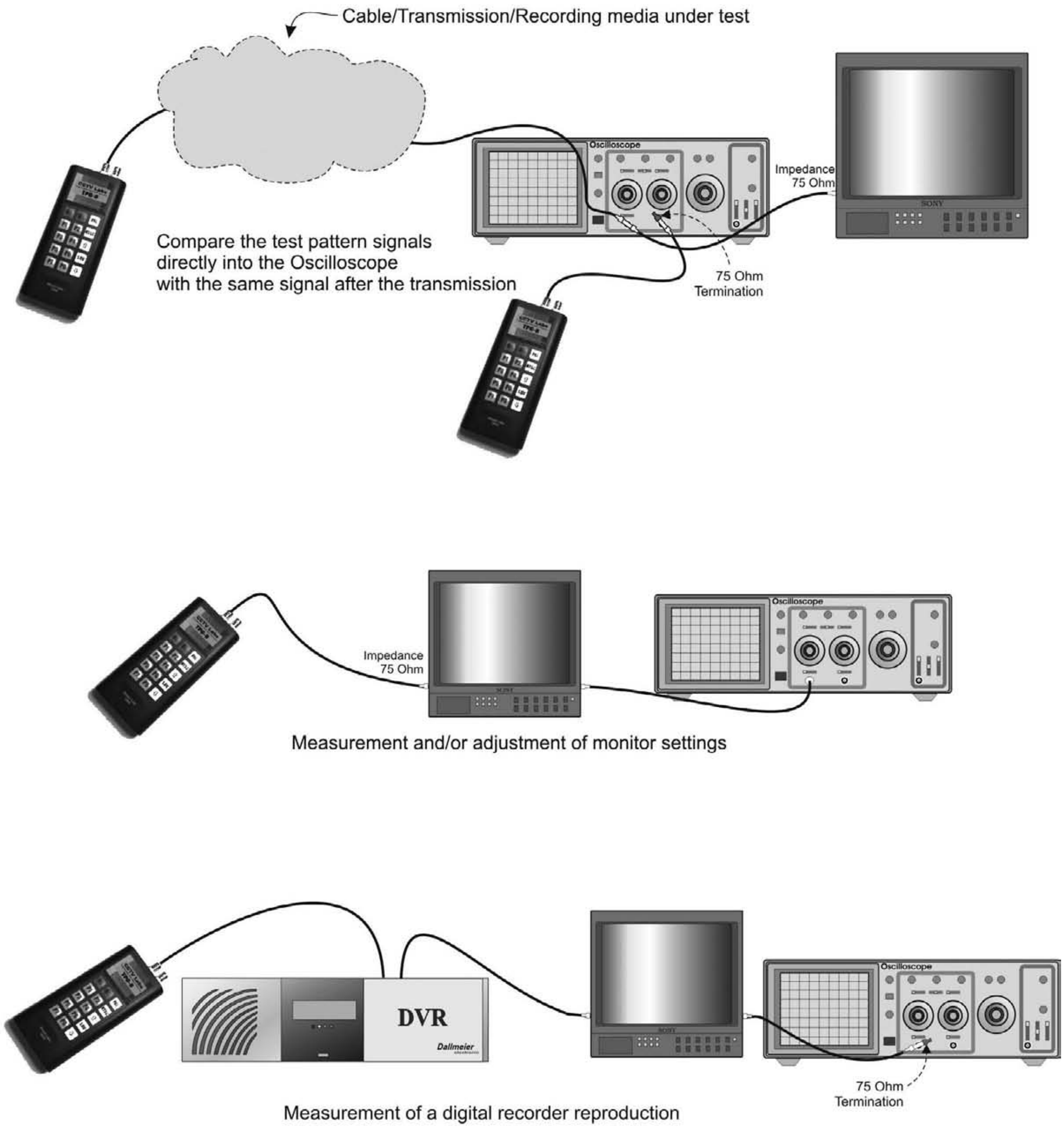
Autonomous operating with fully charged built-in batteries: **over 3 hours.**

Generator Operation range:

- Ambient temperature from 10 to 35º C;
- Max relative moisture 80%;
- Atmosphere pressure range from 84 to 107 kPa (from 630 to 800 mm m.c.).

Generator Dimensions: 190 × 77 × 26 mm^3.

Weight: 300 g.



Some typical connections with the CCTV Labs TPG-8

CCTV Labs test pattern v.3.1

8 indicators of the edge of the 100% screen area
For optimum recording and reproduction
all 8 need to be visible
(*704X576 pixels,requires underscan monitor to verify*)

EBU colour bars 100%
100.0.100.0
(*maximum value for an uncoloured bar / minimum of the same / maximum value for coloured bar / minimum value of the same)*

The large white circle indicates the linearity of the display and/or recording system

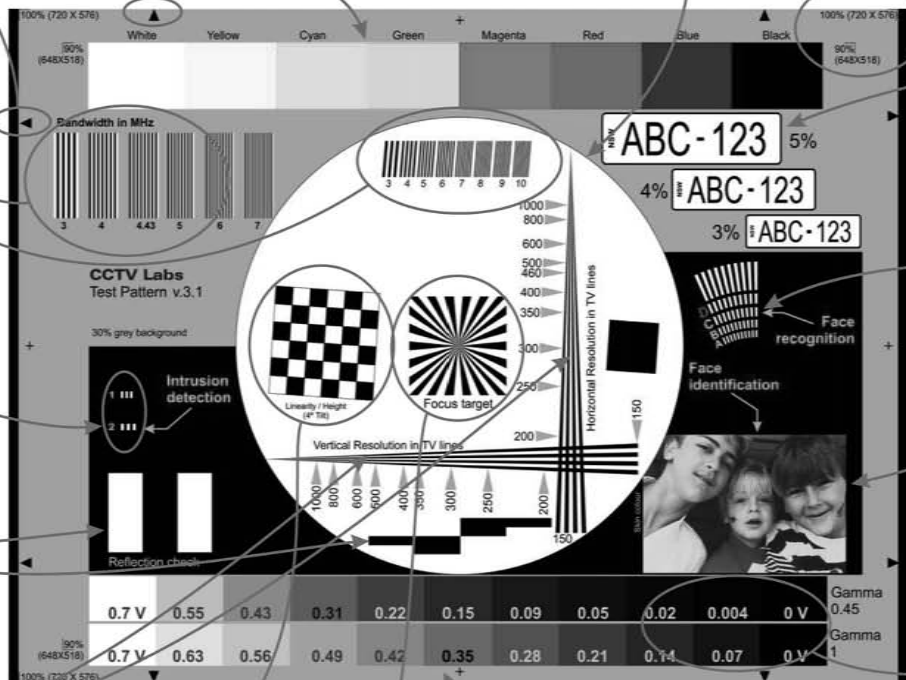
Indicates the percentage and pixel count of the viewing screen

Bandwidth in MegaHertz
(*Lines need to be recogniseable. The tilted bandwidth lines show more natural bandwidth as they are not straight vertical*)

Recognition of license plates as per European and Australian standards
(*at least the 5% numbers need to be legible after transmission and/or recording; if 4% or 3% are legible indicate better quality*)

Intrusion detection as per European and Australian standards
(*at least green bars under "2" need to be legible*)

Face recognition as per European and Australian standards
(*at least green bars under "C" need to be legible; if "B" or "A" are legible indicate better quality*)



Signal reflection due to bad termination can be checked here as well as smearing due to aged monitors

Face identification as per European and Australian standards
(*children faces represent 10% of the screen height*)
Also used to determine compression quality and "natural objects" compression artefacts

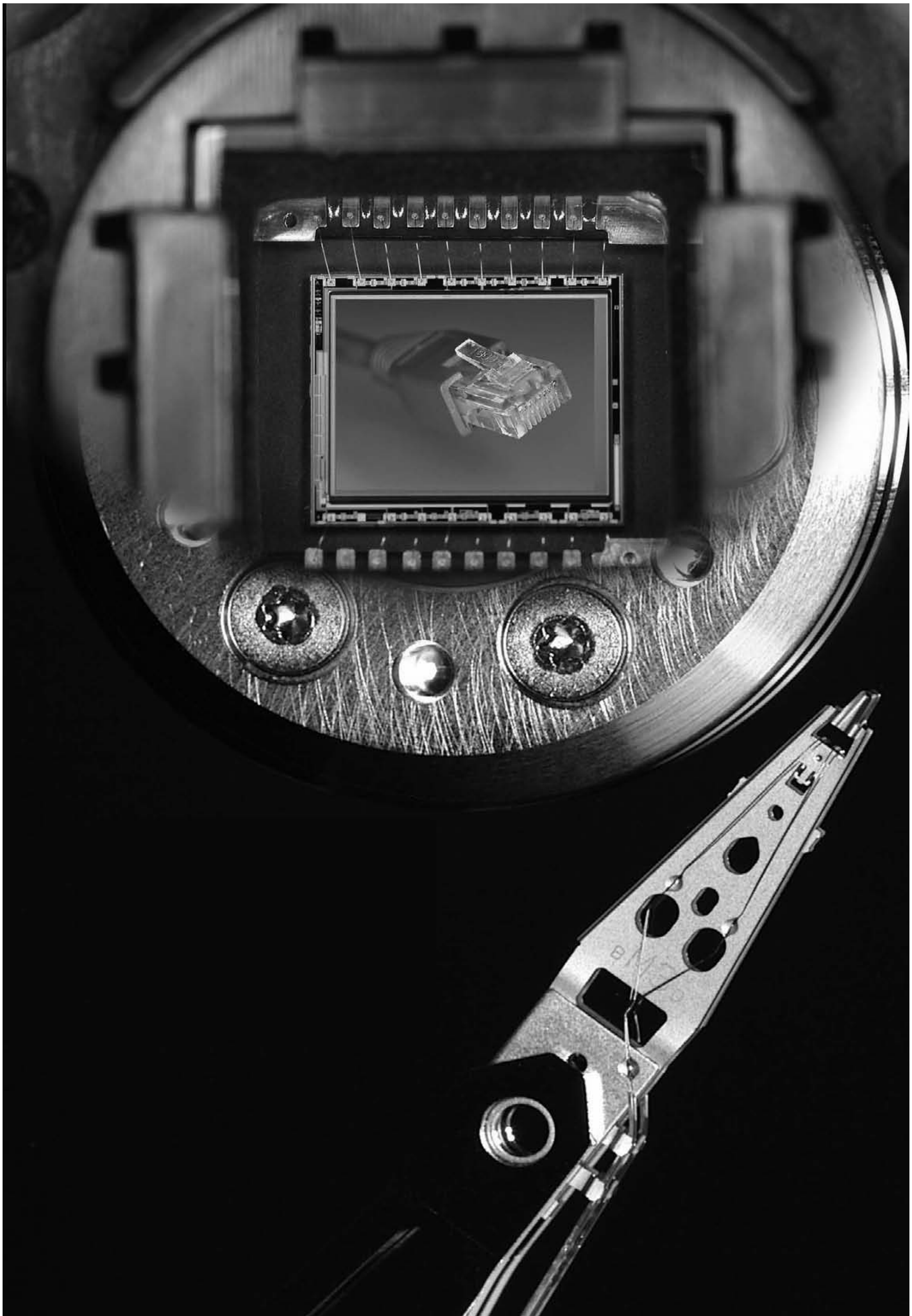
Gamma check (linear or exponential)
(*the numbers in each gray step represent voltage levels relative to the black level that should be measured with an oscilloscope when the signals are terminated correctly*)

Resolution check
(*where four wedges converge to three or two*)

Linearity/Height check

Centre of the test pattern.
Also used to determine TV field or TV frame recording
(*frame recording has smoother edges*)

Use linear or exponential gray scale (depending on the monitor phosphor) to set the optimum contracts and brightness of a monitor
(*all steps need to be distinguishable*)



Appendix A

Common terms used in CCTV

1080i. One of the resolution specs used in the HDTV. 1080i stands for resolution of 1920 × 1080 pixels, and the little "i" means that the video is being interlaced. Other common HDTV resolutions are 720i and 720p.

1080p. Same as above but with progressive scanning.

16:9. A standard TV aspect ratio is 4:3, whereas a Widescreen TV aspect ratio is 16:9. 16:9 fans argue that most movies are shot in a Widescreen aspect ratio, therefore, viewing them on a Widescreen TV is much better. A lot of DVDs that were shot in Widescreen format are available in both 16:9 and 4:3, but you will see the entire recorded picture with 16:9 but probably just a portion of the screen with 4:3. This is known as Pan & Scan, where the area on your TV changes to whichever part of the recording has the most action in it. Widescreen movies should show letterboxed on normal 4:3 TVs.

4:3. A standard TV aspect ratio is 4:3. If you look at a standard TV, you will see that it is almost a square. 4:3 simply means 4 units wide by 3 units tall. Original TV programming shows fine on a 4:3 TV as decades ago, the Television industry used the Academy Standard for TVs.

720i. One of the resolution specs used in the HDTV. 720i stands for resolution of 1280 × 720 pixels, and the magic little "i" means that the video is in interlaced format. Other common HDTV resolutions are 1080i and 720p.

720p. One of the resolution specs used in the HDTV. 720p stands for resolution of 1280 × 720 pixels, and the magic little "p" means that the video is in progressive format. Other common HDTV resolutions are 1080i and 720i.

802.11. A range of IEEE standards covering the usage of wireless internetworking.

Aberration. A term from optics that refers to anything affecting the fidelity of the image in regards to the original scene.

AC. Alternating current.

Activity detection. Refers to a method built into some multiplexers for detecting movement within the camera's field of view (connected to the multiplexer), which is then used to improve camera recording update rate.

AC/DC. Alternating current/direct current.

A/D (AD). Usually refers to analog-to-digital conversion.

ADC. Analog-to-digital conversion. This is usually the very first stage of an electronic device that processes signals into digital format. The signal can be video, audio, control output, and the like.

AGC. Automatic gain control. A section in an electronic circuit that has feedback and regulates a certain voltage level to fall within predetermined margins.

ALC. Automatic light control. A part of the electronics of an automatic iris lens that has a function similar to backlight compensation in photography.

Aliasing. An occurrence of sampled data interference. This can occur in CCD image projection of high spatial frequencies and is also known as Moiré patterning. It can be minimized by a technique known as optical low-pass filtering.

Alphanumeric video generator (also text inserter). A device for providing additional information, normally superimposed on the picture being displayed; this can range from one or two characters to full-screen alphanumeric text. Such generators use the incoming video signal sync pulses as a reference point for the text insertion position, which means if the video signal is of poor quality, the text stability will also be of poor quality.

Amplitude. The maximum value of a varying waveform.

Analog signal. Representation of data by continuously varying quantities. An analog electrical signal has a different value of volts or amperes for electrical representation of the original excitement (sound, light) within the dynamic range of the system.

ANSI. American National Standards Institute.

Anti-aliasing. A procedure employed to eliminate or reduce (by smoothing and filtering) the aliasing effects.

Aperture. The opening of a lens that controls the amount of light reaching the surface of the pickup device. The size of the aperture is controlled by the iris adjustment. By increasing the F-stop number (F/1.4, F/1.8, F/2.8, etc.), less light is permitted to pass to the pickup device.

Apostilb. A photometric unit for measuring luminance where, instead of candelas, lumens are used to measure the luminous flux of a source.

Archive. Long-term off-line storage. In digital systems, pictures are generally archived onto some form of hard disk, magnetic tape, floppy disk, or DAT cartridge.

ARP. Address Resolution Protocol.

Artifacts. Undesirable elements or defects in a video picture. These may occur naturally in the video process and must be eliminated in order to achieve a high-quality picture. The most common are cross-color and cross-luminance.

ASCII. American Standard Code for Information Interchange. A 128-character set that includes the upper-case and lower-case English alphabet, numerals, special symbols, and 32 control codes. A 7-bit binary number represents each character. Therefore, one ASCII-encoded character can be stored in one byte of computer memory.

Aspect ratio. This is the ratio between the width and height of a television or cinema picture display. The present aspect ratio of the television screen is 4:3, which means four units wide by three units high. Such an aspect ratio was elected in the early days of television, when the majority of movies were of the same format. The new, high-definition television format proposes a 16:9 aspect ratio.

Aspherical lens. A lens that has an aspherical surface. It is harder and more expensive to manufacture, but it offers certain advantages over a normal spherical lens.

Astigmatism. The uneven foreground and background blur that is in an image.

Asynchronous. Lacking synchronization. In video, a signal is asynchronous when its timing differs from that of the system reference signal. A foreign video signal is asynchronous before a local frame synchronizer treats it.

ATM. Asynchronous transfer mode. A transporting and switching method in which information does not occur periodically with respect to some reference such as a frame pattern.

ATSC. Advanced Television System Committee (think of it as a modern NTSC). An American committee involved in creating the high definition television standards.

Attenuation. The decrease in magnitude of a wave, or a signal, as it travels through a medium or an electric system. It is measured in decibels (dB).

Attenuator. A circuit that provides reduction of the amplitude of an electrical signal without introducing appreciable phase or frequency distortion.

Auto iris (AI). An automatic method of varying the size of a lens aperture in response to changes in scene illumination.

AWG. American wire gauge. A wire diameter specification based on the American standard. The smaller the AWG number, the larger the wire diameter (see the reference table in Chapter 5).

Back-focus. A procedure of adjusting the physical position of the CCD-chip/lens to achieve the correct focus for all focal length settings (especially critical with zoom lenses).

Back porch. 1. The portion of a video signal that occurs during blanking from the end of horizontal sync to the beginning of active video. 2. The blanking signal portion that lies between the trailing edge of a horizontal sync pulse and the trailing edge of the corresponding blanking pulse. Color burst is located on the back porch.

Balanced signal. In CCTV this refers to a type of video signal transmission through a twisted pair cable. It is called balanced because the signal travels through both wires, thus being equally exposed to the external interference; thus, by the time the signal gets to the receiving end, the noise will be canceled out at the input of a differential buffer stage.

Balun. This is a device used to match or transform an unbalanced coaxial cable to a balanced twisted pair system.

Bandwidth. The complete range of frequencies over which a circuit or electronic system can function with minimal signal loss, usually measured to the point of less than 3 dB. In PAL systems the bandwidth limits the maximum visible frequency to 5.5 MHz, in NTSC to 4.2 MHz. The ITU 601 luminance channel sampling frequency of 13.5 MHz was chosen to permit faithful digital representation of the PAL and NTSC luminance bandwidths without aliasing.

Baseband. The frequency band occupied by the aggregate of the signals used to modulate a carrier before they combine with the carrier in the modulation process. In CCTV the majority of signals are in the baseband.

Baud. Data rate, named after Maurice Emile Baud, which generally is equal to 1 bit/s. Baud is equivalent to bits per second in cases where each signal event represents exactly 1 bit. Typically, the baud settings of two devices must match if the devices are to communicate with one another.

BER. Bit error rate. The ratio of received bits that are in error relative to the total number of bits received, used as a measure of noise-induced distortion in a digital bit stream. BER is expressed as a power of 10. For example, a 1 bit error in 1 million bits is a BER of 10^{-6}.

Betamax. Sony's domestic video recording format, a competitor of VHS.

B-frame. Bidirectionally predictive coded frame (or picture). This terminology is used in MPEG video compression. The B pictures are predicted from the closest two I (intra) or P (predicted) pictures, one in the past and one in the future. They are called bi-directional because they refer to using the past and future images.

Bias. Current or voltage applied to a circuit to set a reference operating level for proper circuit performance, such as the high-frequency bias current applied to an audio recording head to improve linear performance and reduce distortion.

Binary. A base 2 numbering system using the two digits 0 and 1 (as opposed to 10 digits [0–9] in the decimal system). In computer systems, the binary digits are represented by two different voltages or currents, one corresponding to zero and another corresponding to one. All computer programs are executed in binary form.

Bipolar. A signal containing both positive-going and negative-going amplitude. May also contain a zero amplitude state.

B-ISDN. Broadband Integrated Services Digital Network. An improved ISDN, composed of

an intelligent combination of more ISDN channels into one that can transmit more data per second.

Bit. A contraction of binary digit. Elementary digital information that can only be 0 or 1. The smallest part of information in a binary notation system. A bit is a single 1 or 0. A group of bits, such as 8 bits or 16 bits, compose a byte. The number of bits in a byte depends on the processing system being used. Typical byte sizes are 8, 16, and 32.

Bitmap (BMP). A pixel-by-pixel description of an image. Each pixel is a separate element. Also a computer uncompressed image file format.

Bit rate. B/s = Bytes per second, b/s = bits per second. The digital equivalent of bandwidth, bit rate is measured in bits per second. If expressed in bytes per second, multiplied with 8 gives bits per second. It is used to express the data rate at which the compressed bitstream is transmitted. The higher the bit rate, the more information that can be carried.

Blackburst (color-black). A composite color video signal. The signal has composite sync, reference burst, and a black video signal, which is usually at a level of 7.5 IRE (50 mV) above the blanking level.

Black level. A part of the video signal, close to the sync level, but slightly above it (usually 20 mV–50 mV) in order to be distinguished from the blanking level. It electronically represents the black part of an image, whereas the white part is equivalent to 0.7 V from the sync level.

Blanking level. The beginning of the video signal information in the signal's waveform. It resides at a reference point taken as 0 V, which is 300 mV above the lowest part of the sync pulses. Also known as pedestal, the level of a video signal that separates the range that contains the picture information from the range that contains the synchronizing information.

Blooming. The defocusing of regions of a picture where brightness is excessive.

Bluetooth. A wireless data standard, used in a variety of electronic devices for close proximity interconnection (see Chapter 11).

BNC. Bayonet-Neil-Concelman connector. It is the most popular connector in CCTV and broadcast TV for transmitting a basic bandwidth video signal over an RG-59 type coaxial cable.

B-picture. Bidirectionally predictive coded picture. This terminology is used in MPEG video compression. The B pictures are predicted from the closest two I (intra) or P (predicted) pictures, one in the past and one in the future. They are called bi-directional because they refer to using the past and future images.

Braid. A group of textile or metallic filaments interwoven to form a tubular structure that may be applied over one or more wires or flattened to form a strap.

Bridge (network). A more "intelligent" data communications device that connects and enables data packet forwarding between homogeneous networks.

Brightness. In NTSC and PAL video signals, the brightness information at any particular instant in a picture is conveyed by the corresponding instantaneous DC level of active video. Brightness control is an adjustment of setup (black level, black reference).

Burst (color burst). Seven to nine cycles (NTSC) or ten cycles (PAL) of subcarrier placed near the end of horizontal blanking to serve as the phase (color) reference for the modulated color subcarrier. Burst serves as the reference for establishing the picture color.

Bus. In computer architecture, a path over which information travels internally among various components of a system and is available to each of the components.

Byte. A digital word made of 8 bits (zeros and ones).

Cable equalization. The process of altering the frequency response of a video amplifier to compensate for high-frequency losses in coaxial cable.

CAD. Computer-aided design. This usually refers to a design of system that uses computer specialized software.

Candela [cd]. A unit for measuring luminous intensity. One candela is approximately equal to the amount of **light energy** generated by an ordinary candle. Since 1948 a more precise definition of a candela has become: "the luminous intensity of a black body heated up to a temperature at which platinum converges from a liquid state to a solid."

CATV. Community antenna television.

C-band. A range of microwave frequencies, 3.7–4.2 GHz, commonly used for satellite communications.

CCD. Charge-coupled device. The new age imaging device, replacing the old tubes. When first invented in the 1970s, it was initially intended to be used as a memory device. Most often used in cameras, but also in telecine, fax machines, scanners, and so on.

CCD aperture. The proportion of the total area of a CCD chip that is photosensitive.

CCIR. Committée Consultatif International des Radiocommuniqué or, in English, Consultative Committee for International Radio, which is the European standardization body that has set the standards for television in Europe. It was initially monochrome; therefore, today the term *CCIR* usually refers to monochrome cameras that are used in PAL countries.

CCIR 601. An international standard (now renamed to *ITU 601*) for component digital television that was derived from the SMPTE RP1 25 and EBU 3246E standards. ITU 601 defines the sampling systems, matrix values, and filter characteristics for Y, Cr, Cb, and RGB component digital television. It establishes a 4:2:2 sampling scheme at 13.5 MHz for the luminance channel and 6.75 MHz for the chrominance channels with 8-bit digitizing for each channel. These sample frequencies were chosen because they work for both 525-line 60 Hz and 625-line 50 Hz

component video systems. The term 4:2:2 refers to the ratio of the number of luminance channel samples to the number of chrominance channel samples; for every four luminance samples, each chrominance channels is sampled twice.

CCIR 656. The international standard (now renamed to ITU 656) defining the electrical and mechanical interfaces for digital television equipment operating according to the ITU 601 standard. ITU 656 defines both the parallel and serial connector pinouts, as well as the blanking, sync, and multiplexing schemes used in both parallel and serial interfaces.

CCTV. Closed circuit television. Television system intended for only a limited number of viewers, as opposed to broadcast TV.

CCTV camera. A unit containing an imaging device that produces a video signal in the basic bandwidth.

CCTV installation. A CCTV system, or an associated group of systems, together with all necessary hardware, auxiliary lighting, etc., located at the protected site.

CCTV system. An arrangement comprised of a camera and lens with all ancillary equipment required for the surveillance of a specific protected area.

CCVE. Closed circuit video equipment. An alternative acronym for CCTV.

CD. Compact disc. A media standard as proposed by Philips and Sony, where music and data are stored in digital format.

CD-ROM. Compact disk read only memory. The total capacity of a CD-ROM when storing data can be 640 MB or 700 MB.

CDS. Correlated double sampling. A technique used in the design of some CCD cameras that reduces the video signal noise generated by the chip.

CFA. Color filter array. A set of optical pixel filters used in single-chip color CCD cameras to produce the color components of a video signal.

Chip. An integrated circuit in which all the components are micro-fabricated on a tiny piece of silicon or similar material.

Chroma crawl. An artifact of encoded video, also known as dot crawl or cross-luminance, Occurs in the video picture around the edges of highly saturated colors as a continuous series of crawling dots and is a result of color information being confused as luminance information by the decoder circuits.

Chroma gain (chroma, color, saturation). In video, the gain of an amplifier as it pertains to the intensity of colors in the active picture.

Chroma key (color key). A video key effect in which one video signal is inserted in place of

areas of a particular color in another video signal.

Chrominance. The color information of a color video signal.

Chrominance-to-luminance intermodulatlon (crosstalk, cross-modulation). An undesirable change in luminance amplitude caused by superimposition of some chrominance information on the luminance signal. Appears in a TV picture as unwarranted brightness variations caused by changes in color saturation levels.

CIE. Commission Internationale de l'Eclairagé. This is the International Committee for Light, established in 1965. It defines and recommends light units.

CIF. Common Interchange Format, refers to digitized image with pixel count of 352 × 288 (or 240) pixels.

Cladding. The outer part of a fiber optics cable, which is also a fiber but with a smaller material density than the center core. It enables a total reflection effect so that the light transmitted through the internal core stays inside.

Clamping (DC). The circuit or process that restores the DC component of a signal. A video clamp circuit, usually triggered by horizontal synchronizing pulses, reestablishes a fixed DC reference level for the video signal. A major benefit of a clamp is the removal of low-frequency interference, especially power line hum.

Clipping Level. An electronic limit to avoid overdriving the video portion of the television signal.

C-mount. The first standard for CCTV lens screw mounting. It is defined with the thread of 1" (2.54 mm) in diameter and 32 threads/inch, and the back flange-to-CCD distance of 17.526 mm (0.69"). The C-mount description applies to both lenses and cameras. C-mount lenses can be put on both, C-mount and CS-mount cameras; only in the latter case an adaptor is required.

CMYK. Cyan, magenta, yellow, and black. A color encoding system used by printers in which colors are expressed by the "subtractive primaries" (cyan, magenta, and yellow) plus black (called K). The black layer is added to give increased contrast and range on printing presses.

Coaxial cable. The most common type of cable used for copper transmission of video signals. It has a coaxial cross section, where the center core is the signal conductor, while the outer shield protects it from external electromagnetic interference.

Codec. Code/Decode. An encoder plus a decoder is an electronic device that compresses and decompresses digital signals. Codecs usually perform A/D and D/A conversion.

Color bars. A pattern generated by a video test generator, consisting of eight equal-width color bars. Colors are white (75%), black (7.5% setup level), 75% saturated pure colors red, green, and blue, and 75% saturated hues of yellow, cyan, and magenta (mixtures of two colors in 1:1 ratio without third color).

Color carrier. The subfrequency in a color video signal (4.43 MHz for PAL) that is modulated with the color information. The color carrier frequency is chosen so that its spectrum interleaves with the luminance spectrum with minimum interference.

Color difference signal. A video color signal created by subtracting luminance and/or color information from one of the primary color signals (red, green, or blue). In the Betacam color difference format, for example, the luminance (Y) and color difference components (R–Y and B–Y) are derived as follows:

Y = 0.3 Red + 0.59 Green + 0.11 Blue

R–Y = 0.7 Red – 0.59 Green – 0.11 Blue

B–Y = 0.89 Blue – 0.59 Green – 0.3 Red

The G-V color difference signal is not created because it can be reconstructed from the other three signals. Other color difference conventions include SMPTE, EBU-N1 0, and MII. Color difference signals should not be referred to as component video signals. That term is reserved for the RGB color components. In informal usage, the term *component video* is often used to mean color difference signals.

Color field. In the NTSC system, the color subcarrier is phase-locked to the line sync so that on each consecutive line, the subcarrier phase is changed 180º with respect to the sync pulses. In the PAL system, color subcarrier phase moves 90º every frame. In NTSC this creates four different field types, while in PAL there are eight. In order to make clean edits, alignment of color field sequences from different sources is crucial.

Color frame. In color television, four (NTSC) or eight (PAL) properly sequenced color fields compose one color frame.

Color phase. The timing relationship in a video signal that is measured in degrees and keeps the hue of a color signal correct.

Color subcarrier. The 3.58 MHz for NTSC, and 4.43 MHz for PAL signal that carries color information. This signal is superimposed on the luminance level. Amplitude of the color subcarrier represents saturation, and phase angle represents hue.

Color temperature. Indicates the hue of the color. It is derived from photography where the spectrum of colors is based on a comparison of the hues produced when a black body (as in Physics) is heated from red through yellow to blue, which is the hottest. Color temperature measurements are expressed in Kelvin degrees.

Comb filter. An electrical filter circuit that passes a series of frequencies and rejects the frequencies in between, producing a frequency response similar to the teeth of a comb. Used on encoded video to select the chrominance signal and reject the luminance signal, thereby reducing cross-chrominance artifacts or, conversely, to select the luminance signal and reject the chrominance

signal, thereby reducing cross-luminance artifacts. Introduced in the S-VHS concept for a better luminance resolution.

Composite sync. A signal consisting of horizontal sync pulses, vertical sync pulses, and equalizing pulses only, with a no-signal reference level.

Composite video signal. A signal in which the luminance and chrominance information has been combined using one of the coding standards NTSC, PAL, SECAM, and so on.

Concave lens. A lens that has negative focal length – the focus is virtual, and it reduces the objects.

Contrast. A common term used in reference to the video picture dynamic range – the difference between the darkest and the brightest parts of an image.

Convex lens. A convex lens has a positive focal length – the focus is real. It is usually called magnifying glass, since it magnifies the objects.

CPU. Central processing unit. A common term used in computers.

CRO. Cathode ray oscilloscope. See Oscilloscope.

Crosstalk. A type of interference or undesired transmission of signals from one circuit into another circuit in the same system. Usually caused by unintentional capacitance (AC coupling).

CS-Mount. A newer standard for lens mounting. It uses the same physical thread as the C-mount, but the back flange-to-CCD distance is reduced to 12.5 mm in order to have the lenses made smaller, more compact, and less expensive. CS-mount lenses can only be used on CS-mount cameras.

CS-to-C-mount adaptor. An adaptor used to convert a CS-mount camera to C-mount to accommodate a C-mount lens. It looks like a ring 5 mm thick, with a male thread on one side and a female on the other, with 1" diameter and 32 threads/inch. It usually comes packaged with the newer type (CS-mount) of cameras.

CVBS. Composite video bar signal. In broadcast television this refers to the video signal, including the color information and syncs.

D/A (also DA). Opposite to A/D, that is, digital to analog conversion.

Dark current. Leakage signal from a CCD sensor in the absence of incident light.

Dark noise. Noise caused by the random (quantum) nature of the dark current.

DAT (digital audio tape). A system initially developed for recording and playback of digitized audio signals, maintaining signal quality equal to that of a CD. Recent developments in hardware and software might lead to a similar inexpensive system for video archiving, recording, and playback.

dB. Decibel. A logarithmic ratio of two signals or values, usually refers to power, but also voltage and current. When power is calculated, the logarithm is multiplied by 10, while for current and voltage by 20.

DBS. Direct broadcast satellite. Broadcasting from a satellite directly to a consumer user, usually using a small aperture antenna.

DC. Direct current. Current that flows in only one direction, as opposed to AC.

DCT. Discrete cosine transform. Mathematical algorithm used to generate frequency representations of a block of video pixels. The DCT is an invertible, discrete orthogonal transformation between the time and frequency domain. It can be either forward discrete cosine transform (FDCT) or inverse discrete cosine transform (IDCT).

Decoder. A device used to recover the component signals from a composite (encoded) source.

Degauss. To demagnetize. Most often found on CRT monitors.

Delay line. An artificial or real transmission line or equivalent device designed to delay a wave or signal for a specific length of time.

Demodulator. A device that strips the video and audio signals from the carrier frequency.

Depth of field. The area in front of and behind the object in focus that appears sharp on the screen. The depth of field increases with the decrease of the focal length – the shorter the focal length the wider the depth of field. The depth of field is always wider behind the objects in focus.

DHCP. Dynamic Host Configuration Protocol.

Dielectric. An insulating (nonconductive) material.

Differential gain. A change in the subcarrier amplitude of a video signal caused by a change in the luminance level of the signal. The resulting TV picture will show a change in color saturation caused by a simultaneous change in picture brightness.

Differential phase. A change in the subcarrier phase of a video signal caused by a change in the luminance level of the signal. The hue of colors in a scene changes with the brightness of the scene.

Digital disk recorder. A system that allows the recording of video images on a digital disk.

Digital signal. An electronic signal whereby every different value from the real-life excitation (sound, light) has a different value of binary combinations (words) that represent the analog signal.

DIN. Deutsche Industrie-Normen. Germany's standard.

Disk. A flat circular plate, coated with a magnetic material, on which data may be stored by selective magnetization of portions of the surface. May be a flexible, floppy disk or a rigid hard disk. It could also be a plastic compact disk (CD) or digital video disk (DVD).

Distortion. Nonproportional representation of an original.

DMD. Digital micro-mirror device. A new video projection technology that uses chips with a large number of miniature mirrors, whose projection angle can be controlled with digital precision.

DOS. Disk operating system. A software package that makes a computer work with its hardware devices such as hard drive, floppy drive, screen, and keyboard.

Dot pitch. The distance in millimeters between individual dots on a monitor screen. The smaller the dot pitch the better, since it allows for more dots to be displayed and better resolution. The dot pitch defines the resolution of a monitor. A high-resolution CCTV or computer monitor would have a dot pitch of less than 0.3 mm.

Drop-frame time code. SMPTE time code format that continuously counts 30 frames per second but drops two frames from the count every minute except for every tenth minute (drops 108 frames every hour) to maintain the synchronization of time code with clock time. This is necessary because the actual frame rate of NTSC video is 29.94 frames per second rather than an even 30 frames.

DSP. Digital signal processing. It usually refers to the electronic circuit section of a device capable of processing digital signals.

Dubbing. Transcribing from one recording medium to another.

Duplex. A communication system that carries information in both directions is called a duplex system. In CCTV, duplex is often used to describe the type of multiplexer that can perform two functions simultaneously, recording in multiplex mode and playback in multiplex mode. It can also refer to duplex communication between a matrix switcher and a PTZ site driver, for example.

D-VHS. A new standard proposed by JVC for recording digital signals on a VHS video recorder.

DV-Mini. Mini digital video. A new format for audio and video recording on small camcorders, adopted by the majority of camcorder manufacturers. Video and sound are recorded in a digital format on a small cassette (66 × 48 × 12 mm), superseding S-VHS and Hi 8 quality.

Dynamic range. The difference between the smallest amount and the largest amount that a system can represent.

EBU. European Broadcasting Union.

EDTV. Enhanced (Extended) definition television. Usually refers to the progressive scan

transmission of NTSC (also referred to as 480p) and PAL (also referred to as 576p).

EIA. Electronics Industry Association, which has recommended the television standard used in the United States, Canada, and Japan, based on 525 lines interlaced scanning. Formerly known as RMA or RETMA.

Encoder. A device that superimposes electronic signal information on other electronic signals.

Encryption. The rearrangement of the bit stream of a previously digitally encoded signal in a systematic fashion to make the information unrecognizable until restored upon receipt of the necessary authorization key. This technique is used for securing information transmitted over a communication channel with the intent of excluding all other than authorized receivers from interpreting the message. Can be used for voice, video, and other communications signals.

ENG camera. Electronic News Gathering camera. Refers to CCD cameras in the broadcast industry.

EPROM. Erasable and programmable read only memory. An electronic chip used in many different security products that stores software instructions for performing various operations.

Equalizer. Equipment designed to compensate for loss and delay frequency effects within a system. A component or circuit that allows for the adjustment of a signal across a given band.

Ethernet. A local area network used for connecting computers, printers, workstations, terminals, and so on, within the same building. Ethernet operates over twisted wire and coaxial cable at speeds up to 10 Mbps. Ethernet specifies a CSMA/CD (carrier sense multiple access with collision detection). CSMA/CD is a technique of sharing a common medium (wire, coaxial cable) among several devices.

External synchronization. A means of ensuring that all equipment is synchronized to the one source.

FCC. Federal Communications Commission (US).

FFT. Fast Fourier Transformation.

Fiber optics. A technology designed to transmit signals in the form of pulses of light. Fiber optic cable is noted for its properties of electrical isolation and resistance to electrostatic and electromagnetic interference.

Field. Refers to one-half of the TV frame that is composed of either all odd or even lines. In CCIR systems each field is composed of 625/2 = 312.5 lines, in EIA systems 525/2 = 262.5 lines. There are 50 fields/second in CCIR/PAL and 60 in the EIA/NTSC TV system.

Film recorder. A device for converting digital data into film output. Continuous tone recorders produce color photographs as transparencies, prints, or negatives.

Fixed focal length lens. A lens with a predetermined fixed focal length, a focusing control, and a choice of iris functions.

Flash memory. Nonvolatile, digital storage. Flash memory has slower access than SRAM or DRAM.

Flicker. An annoying picture distortion, mainly related to vertical syncs and video fields display. Some flicker normally exists due to interlacing; more apparent in 50 Hz systems (PAL). Flicker also shows when static images are displayed on the screen such as computer-generated text transferred to video. Poor digital image treatment, found in low-quality system converters (going from PAL to NTSC and vice versa), creates an annoying flicker on the screen. There are several electronic methods to minimize flicker.

F-number. In lenses with adjustable irises, the maximum iris opening is expressed as a ratio (focal length of the lens)/(maximum diameter of aperture). This maximum iris will be engraved on the front ring of the lens.

Focal length. The distance between the optical center of a lens and the principal convergent focus point.

Focusing control. A means of adjusting the lens to allow objects at various distances from the camera to be sharply defined.

Foot-candela. An illumination light unit used mostly in American CCTV terminology. It equals 10 times (more precisely, 9.29) the illumination value in luxes.

Fourier Transformation. Mathematical transformation of time domain functions into frequency domain.

Frame. Refers to a composition of lines that make one TV frame. In CCIR/PAL TV system one frame is composed of 625 lines, while in EIA/NTSC TV system of 525 lines. There are 25 frames/second in the CCIR/PAL and 30 in the EIA/NTSC TV system. (See also Field.)

Frame-interline transfer (FIT). Refers to one of the few principles of charge transfer in CCD chips. The other two are interline and frame transfer.

Frame store. An electronic device that digitizes a TV frame (or TV field) of a video signal and stores it in memory. Multiplexers, fast scan transmitters, Quad compressors, DVRs, and even some of the latest color cameras have built-in frame stores.

Frame switcher. Another name for a simple multiplexer, which can record multiple cameras on a single VCR (and play back any camera in full screen) but does not have a mosaic (split-screen) image display.

Frame synchronizer. A digital buffer that, by storage and comparison of sync information to a reference and timed release of video signals, can continuously adjust the signal for any timing errors.

Frame transfer (FT). Refers to one of the three principles of charge transfer in CCD chips. The other two are interline and frame-interline transfer.

Frequency. The number of complete cycles of a periodic waveform that occur in a given length of time. Usually specified in cycles per second (Hertz).

Frequency modulation (FM). Modulation of a sine wave or carrier by varying its frequency in accordance with amplitude variations of the modulating signal.

Front porch. The blanking signal portion that lies between the end of the active picture information and the leading edge of horizontal sync.

FTP. File Transfer Protocol.

Gain. Any increase or decrease in strength of an electrical signal. Gain is measured in terms of decibels or number of times of magnification.

Gamma. A correction of the linear response of a camera in order to compensate for the monitor phosphor screen nonlinear response. It is measured with the exponential value of the curve describing the nonlinearity. A typical monochrome monitor's gamma is 2.2, and a camera needs to be set to the inverse value of 2.2 (which is 0.45) for the overall system to respond linearly (i.e., unity).

Gamut. The range of voltages allowed for a video signal, or a component of a video signal. Signal voltages outside of the range (i.e., exceeding the gamut) may lead to clipping, crosstalk, or other distortions.

Gen-lock. A way of locking the video signal of a camera to an external generator of synchronization pulses.

GB. Gigabyte. Unit of computer memory consisting of about one thousand million bytes (a thousand megabytes). Actual value is 1,073,741,824 bytes.

GHz. GigaHertz. One billion cycles per second.

GND. Ground (electrical).

GOP (Group of Pictures). Used in MPEG video compressions. Refers to a group of pictures composed of Intra, Bi-directional, and Predicted pictures, which make up a logical group that MPEG uses to encode redundnacy.

Gray scale. A series of tones that range from black to white, usually expressed in 10 steps.

Ground loop. An unwanted interference in the copper electrical signal transmissions with shielded cable, which is a result of ground currents when the system has more than one ground.

GUI. Graphical user interface.

H.261. A video conferencing compression standard, typically used in ISDN communications. Works with CIF size images.

H.263. This is a further development of H.261 and has been especially optimized for low data transfer rates below 64 kb/s within the H.320 standard.

H.264. A new video compression which is a coimbined effort of the ITU and MPEG, offering a superior video performance especially for HDTV.

HAD. Hole accumulated diode. A type of CCD sensor with a layer designed to accumulate holes (in the electronic sense), thus reducing noise level.

HDD. Hard disk drive. A magnetic medium for storing digital information on most computers and electronic equipment that process digital data.

HDTV. High-definition digital television. The new standard of high resolution broadcast television with 1920 × 1080 or, 1280 × 720 pixels, and aspect ratio of 16:9. Either one of the two can be an interlaced or progressive scanning, which is indicated by the letter "i" or "p" next to the vertical pixels count, that is, 1080i or 1080p, and, 720i or 720p.

Headend. The electronic equipment located at the start of a cable television system, usually including antennas, earth stations, preamplifiers, frequency converters, demodulators, modulators, and related equipment.

Helical scan. A method of recording video information on a tape, most commonly used in home and professional VCRs.

Herringbone. Patterning caused by driving a color-modulated composite video signal (PAL or NTSC) into a monochrome monitor.

Hertz. A unit that measures the number of certain oscillations per second.

Horizontal drive (also horizontal sync). This signal is derived by dividing subcarrier by 227.5 and then doing some pulse shaping. The signal is used by monitors and cameras to determine the start of each horizontal line.

Horizontal resolution. Chrominance and luminance resolution (detail) expressed horizontally across a picture tube. This is usually expressed as a number of black to white transitions or lines that can be differentiated. Limited by the bandwidth of the video signal or equipment.

Horizontal retrace. At the end of each horizontal line of video, a brief period when the scanning beam returns to the other side of the screen to start a new line.

Horizontal sync pulse. The synchronizing pulse at the end of each video line that determines the start of horizontal retrace.

Housings, environmental. Usually refers to cameras' and lens's containers and associated accessories, such as heaters, washers, and wipers, to meet specific environmental conditions.

HS. Horizontal sync.

HTTP. Hyper-text Transport Protocol.

Hub. Hub connects multiple computers and devices into a LAN.

Hue (tint, phase, chroma phase). One of the characteristics that distinguishes one color from another. Hue defines color on the basis of its position in the spectrum, that is, whether red, blue, green, or yellow.

Hum. A term used to describe an unwanted induction of mains frequency.

Hum bug. Another name for a ground loop corrector.

Hyper-HAD. An improved version of the CCD HAD technology, utilizing on-chip micro-lens technology to provide increased sensitivity without increasing the pixel size.

IDE. Interface device electronics. Software and hardware communication standard for interconnecting peripheral devices to a computer.

I-frames (or pictures). Intra frames. Used in MPEG video compression and refers to the reference pictures, usually compresssed with JPEG image compression.

I/O. Input/Output.

I/P. Input. A signal applied to a piece of electric apparatus or the terminals on the apparatus to which a signal or power is applied.

I^2R. Formula for power in watts (W), where I is current in amperes (A), and R is resistance in ohms (Ω).

IEC. International Electrotechnical Commission (also CEI).

Imaging device. A vacuum tube or solid-state device in which the vacuum tube light-sensitive face plate or solid-state light-sensitive array provides an electronic signal from which an image can be created.

Impedance. A property of all metallic and electrical conductors that describes the total opposition to current flow in an electrical circuit. Resistance, inductance, capacitance, and conductance have various influences on the impedance, depending on frequency, dielectric material around conductors, physical relationship between conductors and external factors. Impedance is often referred to with the letter Z. It is measured in ohms, whose symbol is the Greek letter omega – Ω.

Input. Same as I/P.

Inserter (also alphanumeric video generator). A device for providing additional information, normally superimposed on the picture being displayed; this can range from one or two characters to full-screen alphanumeric text. Usually, such generators use the incoming video signal sync pulses as a reference point for the text insertion position, which means that if the video signal is of poor quality, the text stability will also be of poor quality.

Interference. Disturbances of an electrical or electromagnetic nature that introduce undesirable responses in other electronic equipment.

Interlaced scanning. A technique of combining two television fields in order to produce a full frame. The two fields are composed of only odd and only even lines, which are displayed one after the other but with the physical position of all the lines interleaving each other, hence interlace. This type of television picture creation was proposed in the early days of television to have a minimum amount of information and yet achieve flickerless motion.

Interline transfer. One of the three principles of charge transferring in CCD chips. The other two are frame transfer and frame-interline transfer.

IP. Index of protection. A numbering system that describes the quality of protection of an enclosure from outside influences, such as moisture, dust, and impact.

IPv4. The most common IP address type is the IPv4 which consists of 4 bytes (32 bits).

IPv6. The new IP address type which offers a much larger number of addresses, and consists of 16 bytes (128 bits) long.

IRE. Institute of Radio Engineers. Units of measurement dividing the area from the bottom of sync to peak white level into 140 equal units. 140 IRE equals $1V_{pp}$. The range of active video is 100 IRE.

IR light. Infrared light, invisible to the human eye. It usually refers to wavelengths longer than 700 nm. Monochrome (B/W) cameras have extremely high sensitivity in the infrared region of the light spectrum.

Iris. A means of controlling the size of a lens aperture and therefore the amount of light passing through the lens.

ISDN. Integrated Services Digital Network. The newer generation telephone network, which uses 64 kb/s digital transmission. Being a digital network, the signal bandwidth is not expressed in kHz, but rather with a transmission speed.

ISO. International Standardization Organization.

ITU. International Telecommunications Union.

JPEG. Joint Photographic Experts Group. A group that has recommended a compression algorithm for still digital images that can compress with ratios of over 10:1. Also the name of the format itself.

kb/s. Kilobits per second. Thousand bits per second. Also written as kbps.

Kelvin. One of the basic physical units of measurement for temperature. The scale is the same as the Celsius, but the 0º K starts from -273º C, called *absolute zero*. Also the unit of measurement of the temperature of light is expressed in Kelvins or K. In color recording, light temperature affects the color values of the lights and the scene that they illuminate.

K factor. A specification rating method that gives a higher factor to video disturbances that cause the most observable picture degradation.

kHz. Kilohertz. Thousand Hertz.

Kilobaud. A unit of measurement of data transmission speed equaling 1000 baud.

Kilobyte. 1024 bytes.

Lambertian source or surface. A surface is called a Lambert radiator or reflector (depending on whether the surface is a primary or a secondary source of light) if it is a perfectly diffusing surface.

LAN. Local Area Network. A short-distance data communications network (typically within a building or campus) used to link together computers and peripheral devices (such as printers, CD ROMs, and modems) under some form of standard control.

Laser. Light amplification by stimulated emission of radiation. A laser produces a very strong and coherent light of a single frequency.

LCD. Liquid crystal display. A screen for displaying text/graphics based on a technology called liquid crystal, where minute currents change the reflectiveness or transparency of the screen.

LED. Light-emitting diode. A semiconductor that produces light when a certain low voltage is applied to it in one direction.

Lens. An optical device for focusing a desired scene onto the imaging device in a CCTV camera.

Level. When relating to a video signal, it refers to the video level in volts. In CCTV optics, it refers to the auto iris level setting of the electronics that processes the video signal in order to open or close the iris.

Line-locked. In CCTV, this usually refers to multiple cameras being powered by a common alternative current (AC) source (either 24 V AC, 110 V AC, or 240 V AC) and consequently

having their field frequencies locked to the same AC source frequency (50 Hz in CCIR systems and 60 Hz in EIA systems).

Lumen [lm]. A light intensity produced by the luminosity of 1 candela in one steradian of a solid angle (approximately 57º squared).

Luminance. 1. Refers to the video signal information about the scene brightness. The color video picture information contains two components, luminance (brightness and contrast) and chrominance (hue and saturation). 2. It also refers to the photometric quantity of light radiation.

LUT. Look-up table. A cross-reference table in the computer memory that transforms raw information from the scanner or computer and corrects values to compensate for weakness in equipment or for differences in emulsion types.

Lux [lx]. Light unit for measuring illumination. It is defined as the illumination of a surface when the luminous flux of 1 lumen falls on an area of 1 m^2. It is also known as lumen per square meter, or meter-candelas.

MAC. 1. Multiplexed analog components. A system in which the components are time multiplexed into one channel using time domain techniques. The components are kept separate by being sent at different times through the same channel. There are many different MAC formats and standards. 2. Media Access Control address. In computer networking, this is the physical address of each network card.

Manual iris. A manual method of varying the size of a lens's aperture.

Matrix. A logical network configured in a rectangular array of intersections of input/outputs.

Matrix switcher. A device for switching more than one camera, VCR, DVR, video printer, and the like, to more than one monitor, VCR, DVR, video printer and so on.

MATV. Master antenna television.

MB. Megabyte. Unit of measurement for computer memory consisting of approximately one million bytes. Actual value is 1,048,576 bytes. Kilobyte × Kilobyte = Megabyte.

Mb/s. Megabits per second. Million bits per second. Also written as Mbps.

MB/s. Megabytes per second. Million bytes per second or 8 million hits per second. Also written as MBps.

MHz. Megahertz. One million hertz.

Microwave. One definition refers to the portion of the electromagnetic spectrum that ranges between 300 MHz and 3000 GHz. The other definition is when referring to the transmission media where microwave links are used. Frequencies in microwave transmission are usually between 1 GHz and 12 GHz.

MOD. Minimum object distance. Feature of a fixed or a zoom lens that indicates the closest distance an object can be from the lens's image plane, expressed in meters. Zoom lenses have MOD of around 1 m, while fixed lenses usually have much less, depending on the focal length.

Modem. This popular term is made up of two words: modulate and demodulate. The function of a modem is to connect a device (usually computer) via a telephone line to another device with a modem.

Modulation. The process by which some characteristic (i.e., amplitude, phase) of one RF wave is varied in accordance with another wave (message signal).

Moiré pattern. An unwanted effect that appears in the video picture when a high-frequency pattern is looked at with a CCD camera that has a pixel pattern close (but lower) to the object pattern.

Monochrome. Black-and-white video. A video signal that represents the brightness values (luminance) in the picture but not the color values (chrominance).

MPEG. Motion Picture Experts Group. An ISO group of experts that has recommended manipulation of digital motion images. Today there are a couple of MPEG recommendations, of which the most well known are MPEG-1, MPEG-2, and MPEG-4. The MPEG-2 is widely accepted for digital broadcast television, as well as DVD. MPEG-4 is popular for Internet video streaming and CCTV remote surveillance.

MPEG-1. Video compression standard, progressive scanned images with audio. Bit rate is from 1.5 Mbps up to 3.5 Mbps.

MPEG-2. The standard for compression of progressive scanned and interlaced video signals with high-quality audio over a large range of compression rates with a range of bit rates from 1.5 to 30 Mb/s. Accepted as a HDTV and DVD standard of video/audio encoding.

MPEG-4. Modern video compression, uses wider bit rates than MPEG-2, and starts as low as 9.6 kb/s. It works with objects as a new category in video processing.

MPEG-7. Not really a video compression as such, but rather defines an interoperable framework for content descriptions way beyond the traditional "metadata."

MPEG-21. The MPEG-21 goal is to describe a "big picture" of how different elements to build an infrastructure for the delivery and consumption of multimedia content relate to each other.

Multicasting (in networking). Multicasting is an operational mode, whereby a node sends a packet addressed to a special group address.

NIC (Network Interface Card). Every computer (and most other devices) connects to a network through a NIC.

NNTP. Network News Transport Protocol.

Noise. An unwanted signal produced by all electrical circuits working above the absolute zero. Noise cannot be eliminated but only minimized.

Non-drop frame time code. SMPTE time code format that continuously counts a full 30 frames per second. Because NTSC video does not operate at exactly 30 frames per second, non-drop-frame time code will count 108 more frames in one hour than actually occur in the NTSC video in one hour. The result is incorrect synchronization of time code with clock time. The drop-frame time code solves this problem by skipping or dropping 2 frame numbers per minute, except at the tens of the minute count.

Noninterlaced. The process of scanning whereby every line in the picture is scanned during the vertical sweep.

NTSC. National Television System Committee. American committee that set the standards for analog color television as used in the United States, Canada, Japan, and parts of South America. NTSC television uses a 3.57945 MHz subcarrier whose phase varies with the instantaneous hue of the televised color and whose amplitude varies with the instantaneous saturation of the color. NTSC employs 525 lines per frame and 59.94 fields per second. NTSC is now renamed to ATSC, for Advanced Television System Committee.

Numerical aperture. A number that defines the light-gathering ability of a specific fiber. The numerical aperture is equal to the sine of the maximum acceptance angle.

O/P. Output.

Objective. The very first optical element at the front of a lens.

Ocular. The very last optical element at the back of a lens (the one closer to the CCD chip).

Ohm. The unit of resistance. The electrical resistance between two points of a conductor where a constant difference of potential of 1 V applied between these points produces in the conductor a current of 1 A, the conductor not being the source of any electromotive force.

Oscilloscope (also CRO, from cathode ray oscilloscope). An electronic device that can measure the signal changes versus time. A must for any CCTV technician.

OSI layers (in networking). An Open System Interconnection reference model introduced by ISO, which defines seven layers of networking.

Overscan. A video monitor condition in which the raster extends slightly beyond the physical edges of the CRT screen, cutting off the outer edges of the picture.

Output impedance. The impedance a device presents to its load. The impedance measured at the output terminals of a transducer with the load disconnected and all impressed driving forces taken as zero.

PAL. Phase alternating line. Describes the color phase change in a PAL color signal. PAL is a European color TV system featuring 625 lines per frame, 50 fields per second, and a 4.43361875-MHz subcarrier. Used mainly in Europe, China, Malaysia, Australia, New Zealand, the Middle East, and parts of Africa. PAL-M is a Brazilian color TV system with phase alternation by line, but using 525 lines per frame, 60 fields per second, and a 3.57561149 MHz subcarrier.

Pan and tilt head (P/T head). A motorized unit permitting vertical and horizontal positioning of a camera and lens combination. Usually, 24 V AC motors are used in such P/T heads, but also 110 V AC (i.e., 240 V AC units can be ordered).

Pan unit. A motorized unit permitting horizontal positioning of a camera.

Peak-to-peak (pp). The amplitude (voltage) difference between the most positive and the most negative excursions (peaks) of an electrical signal.

Pedestal. In the video waveform, the signal level corresponding to black. Also called setup.

P-frames (or pictures). Prediction-coded pictures used in MPEG video compression. It describes pictures that are coded using motion-compensated prediction from the past I reference picture. See also B-frames; I-frames.

Phot. A photometric light unit for very strong illumination levels. One phot is equal to 10,000 luxes.

Photodiode. A type of semiconductor device in which a PN junction diode acts as a photosensor.

Photo-effect. Also known as photoelectric-effect. This refers to a phenomenon of ejection of electrons from a metal whose surface is exposed to light.

Photon. A representative of the quantum nature of light. It is considered as the smallest unit of light.

Photopic vision. The range of light intensities, from 10^5 lux down to nearly 10^{-2} lux, detectable by the human eye.

Pinhole lens. A fixed focal-length lens, for viewing through a very small aperture, used in discrete surveillance situations. The lens normally has no focusing control but offers a choice of iris functions.

Pixel. Derived from picture element. Usually refers to the CCD chip unit picture cell. It consists of a photosensor plus its associated control gates.

Phase locked loop (PLL). A circuit containing an oscillator whose output phase or frequency locks onto and tracks the phase or frequency of a reference input signal. To produce the locked condition, the circuit detects any phase difference between the two signals and generates a

correction voltage that is applied to the oscillator to adjust its phase or frequency.

Photo multiplier. A highly light-sensitive device. Advantages are its fast response, good signal-to-noise ratio, and wide dynamic range. Disadvantages are fragility (vacuum tube), high voltage, and sensitivity to interference.

Pixel or picture element. The smallest visual unit that is handled in a raster file, generally a single cell in a grid of numbers describing an image.

Plumbicon. Thermionic vacuum tube developed by Philips, using a lead oxide photoconductive layer. It represented the ultimate imaging device until the introduction of CCD chips.

Polarizing filter. An optical filter that transmits light in only one direction (perpendicular to the light path), out of 360° possible. The effect is such that it can eliminate some unwanted bright areas or reflections, such as when looking through a glass window. In photography, polarizing filters are used very often to darken a blue sky.

POTS. Plain old telephone service. The telephone service in common use throughout the world today. Also known as PSTN.

PPP. Point-to-Point Protocol.

Preset positioning. A function of a pan and tilt unit, including the zoom lens, where a number of certain viewing positions can be stored in the system's memory (usually this is in the PTZ site driver) and recalled when required, either upon an alarm trigger, programmed or manual recall.

Primary colors. A small group of colors that, when combined, can produce a broad spectrum of other colors. In television, red, green, and blue are the primary colors from which all other colors in the picture are derived.

Principal point. One of the two points that each lens has along the optical axis. The principal point closer to the imaging device (CCD chip in our case) is used as a reference point when measuring the focal length of a lens.

PROM. Programmable read only memory. A ROM that can be programmed by the equipment manufacturer (rather than the PROM manufacturer).

Protocol. A specific set of rules, procedures, or conventions relating to format and timing of data transmission between two devices. A standard procedure that two data devices must accept and use to be able to understand each other. The protocols for data communications cover such things as framing, error handling, transparency, and line control.

PSTN. Public switched telephone network. Usually refers to the plain old telephone service, also known as POTS.

PTZ camera. Pan, tilt, and zoom camera.

PTZ site driver (or receiver or decoder). An electronic device, usually a part of a video matrix switcher, which receives digital, encoded control signals in order to operate pan, tilt, zoom, and focus functions.

Pulse. A current or voltage that changes abruptly from one value to another and back to the original value in a finite length of time. Used to describe one particular variation in a series of wave motions.

QAM. Quadrature amplitude modulation. Method for modulating two carriers. The carriers can be analog or digital.

Quad compressor (also split-screen unit). Equipment that simultaneously displays parts or more than one image on a single monitor. It usually refers to four quadrants display.

Radio frequency (RF). A term used to describe incoming radio signals to a receiver or outgoing signals from a radio transmitter (above 150 Hz). Even though they are not properly radio signals, TV signals are included in this category.

RAM. Random access memory. Electronic chips, usually known as memory, holding digital information while there is power applied to it. Its capacity is measured in kilobytes. This is the computer's work area.

RAID. Redundant arrays of independent disks. This a technology of connecting a number of hard drives into one mass storage device, which can be used, among other things, for digital recording of video images. There are RAID-0 through to RAID-6. See more in Chapter 9.

Random interlace. In a camera that has a free-running horizontal sync as opposed to a 2:1 interlace type that has the sync locked and therefore has both fields in a frame interlocked together accurately.

Registration. An adjustment associated with color sets and projection TVs to ensure that the electron beams of the three primary colors of the phosphor screen are hitting the proper color dots/stripes.

Resolution. A measure of the ability of a camera or television system to reproduce detail. The number of picture elements that can be reproduced with good definition.

Retrace. The return of the electron beam in a CRT to the starting point after scanning. During retrace, the beam is typically turned off. All of the sync information is placed in this invisible portion of the video signal. May refer to retrace after each horizontal line or after each vertical scan (field).

Remote control. A transmitting and receiving of signals for controlling remote devices such as pan and tilt units, lens functions, wash and wipe control, and the like.

RETMA. Former name of the EIA association. Some older video test charts carry the name RETMA Chart.

RF signal. Radio frequency signal that belongs to the region up to 300 GHz.

RG-11. A video coaxial cable with 75 Ω impedance and much thicker diameter than the popular RG-59 (of approximately 12 mm). With RG-11 much longer distances can be achieved (at least twice the RG-59), but it is more expensive and harder to work with.

RG-58. A coaxial cable designed with 50 Ω impedance; therefore, not suitable for CCTV. Very similar to RG-59, only slightly thinner.

RG-59. A type of coaxial cable that is most common in use in small to medium-size CCTV systems. It is designed with an impedance of 75 Ω. It has an outer diameter of around 6 mm and it is a good compromise between maximum distances achievable (up to 300 m for monochrome signal and 250 m for color) and good transmission.

Rise time. The time taken for a signal to make a transition from one state to another; usually measured between the 10% and 90% completion points of the transition. Shorter or faster rise times require more bandwidth in a transmission channel.

RMS. Root mean square. A measure of effective (as opposed to peak) voltage of an AC waveform. For a sine wave it is 0.707 times the peak voltage. For any periodic waveform, it is the square root of the average of the squares of the values through one cycle.

ROM. Read only memory. An electronic chip, containing digital information that does not disappear when power is turned off.

Router. A specialized computer that sends messages to their destinations along thousands of pathways.

Routing switcher. An electronic device that routes a user-supplied signal (audio, video, etc.) from any input to any user-selected output. This is a broadcast term for matrix switchers, as we know them in CCTV.

RS-125. A SMPTE parallel component digital video standard.

RS-170. A document prepared by the Electronics Industries Association describing recommended practices for NTSC color television signals in the United States.

RS-232. A serial format of digital communication where only two wires are required. It is also known as a serial data communication. The RS-232 standard defines a scheme for asynchronous communications, but it does not define how the data should be represented by the bits, that is, it does not define the overall message format and protocol. It is often used in CCTV communications between keyboards and matrix switchers or between matrix switchers and PTZ site drivers. The advantage of RS-232 over others is its simplicity and use of only two wires, but it is limited with

distance. Typically, maximum 15 m is recommended.

RS-422. A serial data communication protocol which specifies 4-wire, full-duplex, differential line, multi-drop communications. It provides for balanced data transmission with unidirectional, nonreversible, terminated or nonterminated transmission lines. This is an advanced format of digital communication when compared to RS-232. The signal transmitted is read at the receiving end as the difference between the two wires without common earth. So if there is noise induced along the line, it will be canceled out. The RS-422 can drive lines of 1200 m in length and distribute data to up to 10 receivers, with data rate of up to 100 kb/s.

RS-485. This is a more advanced format compared to RS-422. It is an electrical specification of a two-wire, half-duplex, multipoint serial connection. The major improvement is in the number of receivers up to 32 that can be driven with this format. In contrast to RS-422, which has a single driver circuit which cannot be switched off, RS-485 drives need to be put in transmit mode explicitly by asserting a signal to the driver. This allows RS-485 to implement star network topologies using only two lines. RS-485, like RS-422, can be made full-duplex by using four wires, however, since RS-485 is a multipoint specification, this is not necessary in many cases.

Saturation (in color). The intensity of the colors in the active picture. The degree by which the eye perceives a color as departing from a gray or white scale of the same brightness. A 100% saturated color does not contain any white; adding white reduces saturation. In NTSC and PAL video signals, the color saturation at any particular instant in the picture is conveyed by the corresponding instantaneous amplitude of the active video subcarrier.

Scanner. 1. When referring to a CCTV device, it is the pan only head. 2. When referring to an imaging device, it is the device with CCD chip that scans documents and images.

Scanning. The rapid movement of the electron beam in the CRT of a monitor or television receiver. It is formatted line-for-line across the photosensitive surface to produce or reproduce the video picture. When referred to a PTZ camera, it is the panning or the horizontal camera motion.

Scene illumination. The average light level incident upon a protected area. Normally measured for the visible spectrum with a light meter having a spectral response corresponding closely to that of the human eye and is quoted in lux.

Scotopic vision. Illumination levels below 10^{-2} lux, thus invisible to the human eye.

SCSI. Small computer systems interface. A computer standard that defines the software and hardware methods of connecting more external devices to a computer bus.

SECAM. Sequential Couleur Avec Memoire, sequential color with memory. A color television system with 625 lines per frame (used to be 819) and 50 fields per second developed by France and the former U.S.S.R. Color difference information is transmitted sequentially on alternate lines as an FM signal.

Serial data. Time-sequential transmission of data along a single wire. In CCTV, the most common

method of communicating between keyboards and the matrix switcher and also controlling PTZ cameras.

Serial interface. A digital communications interface in which data are transmitted and received sequentially along a single wire or pair of wires. Common serial interface standards are RS-232 and RS-422.

Serial port. A computer I/O (input/output) port through which the computer communicates with the external world. The standard serial port is RS-232 based and allows bidirectional communication on a relatively simple wire connection as data flow serially.

Sidebands. The frequency bands on both sides of a carrier within which the energy produced by the process of modulation is carried.

Signal-to-noise ratio (S/N). An S/N ratio can be given for the luminance signal, chrominance signal, and audio signal. The S/N ratio is the ratio of noise to actual total signal, and it shows how much higher the signal level is than the level of noise. It is expressed in decibels (dB), and the bigger the value is, the crisper and clearer the picture and sound will be during playback. An S/N ratio is calculated with the logarithm of the normal signal and the noise RMS value.

Silicon. The material of which modern semiconductor devices are made.

Simplex. In general, simplex refers to a communications system that can transmit information in one direction only. In CCTV, simplex is used to describe a method of multiplexer operation whereby only one function can be performed at a time (e.g., either recording or playback individually).

Single-mode fiber. An optical glass fiber that consists of a core of very small diameter. A typical single-mode fiber used in CCTV has a 9 µm core and a 125 µm outer diameter. Single-mode fiber has less attenuation and therefore transmits signals at longer distances (up to 70 km). Such fibers are normally used only with laser sources because of their very small acceptance cone.

Skin effect. The tendency of alternating current to travel only on the surface of a conductor as its frequency increases.

SLIP. Serial Line Internet Protocol.

Slow scan. The transmission of a series of frozen images by means of analog or digital signals over limited bandwidth media, usually telephone.

Smear. An unwanted side effect of vertical charge transfer in a CCD chip. It shows vertical bright stripes in places of the image where there are very bright areas. In better cameras smear is minimized to almost undetectable levels.

SMPTE. Society of Motion Picture and Television Engineers.

SMPTE time code. In video editing, time code that conforms to SMPTE standards. It consists of an 8-digit number specifying hours: minutes: seconds: frames. Each number identifies one frame on a videotape. SMPTE time code may be of either the drop-frame or non-drop-frame type.

SMTP. Simple Mail Transfer Protocol.

SNMP. Simple Network Management Protocol.

Snow. Random noise on the display screen, often resulting from dirty heads or weak broadcast video reception.

S/N ratio. See Signal-to-noise ratio.

Spectrum. In electromagnetics, spectrum refers to the description of a signal's amplitude versus its frequency components. In optics, spectrum refers to the light frequencies composing the white light which can be seen as rainbow colors.

Spectrum analyzer. An electronic device that can show the spectrum of an electric signal.

SPG. Sync pulse generator. A source of synchronization pulses.

Split-screen unit (quad compressor). Equipment that simultaneously displays parts or more than one image on a single monitor. It usually refers to four quadrants' display.

Staircase (in television). Same as color bars. A pattern generated by the TV generator, consisting of equal-width luminance steps of 0, +20, +40, +60, +80, and +100 IRE units and a constant amplitude chroma signal at color burst phase. Chroma amplitude is selectable at 20 IRE units (low stairs) or 40 IRE units (high stairs). The staircase pattern is useful for checking linearity of luminance and chroma gain, differential gain, and differential phase.

Start bit. A bit preceding the group of bits representing a character used to signal the arrival of the character in asynchronous transmission.

Subcarrier (SC). Also known as SC: 3.58 MHz for NTSC, 4.43 MHz for PAL. These are the basic signals in all NTSC and PAL sync signals. It is a continuous sine wave, usually generated and distributed at 2V in amplitude, and having a frequency of 3.579545 MHz (NTSC) and 4.43361875 MHz (PAL). Subcarrier is usually divided down from a primary crystal running at 14.318180 MHz, for example, in NTSC, and that divided by 4 is 3.579545. Similar to PAL. All other synchronizing signals are directly divided down from subcarrier.

SVGA. Super Video Graphic Array offering 800 × 600 pixels of resolution.

S-VHS. Super VHS format in video recording. A newer standard proposed by JVC, preserving the downwards compatibility with the VHS format. It offers much better horizontal resolution up to 400 TV lines. This is mainly due to the color separation techniques, high-quality video heads, and better tapes. S-VHS is usually associated with Y/C separated signals.

Switch (network). A network switch is an "intelligent" data communication device used in connecting computers in networks, and is more common and a successor to the network bridge.

SXGA. Computer screen resolution offering 1400 × 1050 pixels.

Sync. Short for synchronization pulse.

Sync generator (sync pulse generator, SPG). Device that generates synchronizing pulses needed by video source equipment to provide proper equipment video signal timing. Pulses typically produced by a sync generator could be subcarrier, burst flag, sync, blanking, H and V drives, and color black. Most commonly used in CCTV are H and V drives.

T1. A digital transmission link with a capacity of 1.544 Mbps. T1 uses two pairs of normal twisted wires. T1 lines are used for connecting networks across remote distances. Bridges and routers are used to connect LANs over T1 networks.

T1 channels. In North America, a digital transmission channel carrying data at a rate of 1.544 million bits per second. In Europe, a digital transmission channel carrying data at a rate of 2.048 million bits per second. AT&T term for a digital carrier facility used to transmit a DS-1 formatted digital signal at 1.544 Mbps.

T3 channels. In North America, a digital channel that communicates at 45.304 Mbps commonly referred to by its service designation of DS-3.

TBC. Time base correction. Synchronization of various signals inside a device such as a multiplexer or a time base corrector.

TCP/IP. Transmission Control Protocol/Internet Protocol.

TDG. Time and date generator.

TDM. Time division multiplex. A time-sharing of a transmission channel by assigning each user a dedicated segment of each transmission cycle.

Tearing. A lateral displacement of the video lines due to sync instability. It appears as though parts of the images have been torn away.

Teleconferencing. Electronically linked meeting conducted among groups in separate geographic locations.

Telemetry. Remote controlling system of, usually, digital encoded data, intended to control pan, tilt, zoom, focus, preset positions, wash, wipe, and the like. Being digital, it is usually sent via twisted pair cable or coaxial cable together with the video signal.

Termination. This usually refers to the physical act of terminating a cable with a special connector,

which for coaxial cable is usually BNC. For fiber optic cable this is the ST connector. It can also refer to the impedance matching when electrical transmission is in use. This is especially important for high-frequency signals, such as the video signal, where the characteristic impedance is accepted to be 75 Ω.

TFT. Thin-film-transistor. This technology is used mainly for manufacturing flat computer and video screens that are superior to the classic LCD screens. Color quality, fast response time, and resolution are excellent for video.

Time-lapse VCR (TL VCR). A video recorder, most often in VHS format, that can prolong the video recording on a single tape up to 960 hours (this refers to a 180 min tape). This type of VCR is often used in CCTV systems. The principle of operation is very simple – instead of having the videotape travel at a constant speed of 2.275 cm/s (which is the case with the domestic models of VHS VCRs), it moves with discrete steps that can be controlled. Time-lapse VCRs have a number of other special functions that are very useful in CCTV, such as external alarm trigger, time and date superimposed on the video signal, and alarm search.

Time-lapse video recording. The intermittent recording of video signals at intervals to extend the recording time of the recording medium. It is usually measured in reference to a 3-hr (180 min) tape.

Time multiplexing. The technique of recording several cameras onto one time-lapse VCR by sequentially sending camera pictures with a timed interval delay to match the time lapse mode selected on the recorder.

T-pulse to bar. A term relating to the frequency response of video equipment. A video signal containing equal-amplitude T-pulse and bar portions is passed through the equipment, and the relative amplitudes of the T-pulse and bar are measured at the output. A loss of response is indicated when one portion of the signal is lower in amplitude than the other.

Tracking. The angle and speed at which the tape passes the video heads.

Transcoder. A device that converts one form of encoded video to another, for example, to convert NTSC video to PAL. Sometimes mistakenly used to mean translator.

Transducer. A device that converts one form of energy into another. For example, in fiber optics, a device that converts light signals into electrical signals.

Translator. A device used to convert one component set to another (e.g., to convert Y, R-Y, B-Y signals to RGB signals).

Transponder. The electronics of a satellite that receives an uplinked signal from the Earth, amplifies it, converts it to a different frequency, and returns it to the Earth.

TTL. 1. Transistor-transistor logic. A term used in digital electronics mainly to describe the ability of a device or circuit to be connected directly to the input or output of digital equipment.

Such compatibility eliminates the need for interfacing circuitry. TTL signals are usually limited to two states, low and high, and are thus much more limited than analog signals. 2. Thru-the-lens viewing or color measuring.

Twisted-pair. A cable composed of two small insulated conductors twisted together. Since both wires have nearly equal exposure to any interference, the differential noise is slight.

UDP. User Datagram Protocol.

UHF signal. Ultrahigh-frequency signal. In television it is defined to belong in the radio spectrum between 470 MHz and 850 MHz.

Unbalanced signal. In CCTV, this refers to a type of video signal transmission through a coaxial cable. It is called unbalanced because the signal travels through the center core only, while the cable shield is used for equating the two voltage potentials between the coaxial cable ends.

Underscan. Decreases raster size H and V so that all four edges of the picture are visible on the monitor.

UPS. Uninterruptible power supply. These are power supplies used in the majority of high security systems, whose purpose is to back up the system for at least 10 minutes without mains power. The duration of this depends on the size of the UPS, usually expressed in VA (volt-amperes), and the current consumption of the system itself.

UTP. Unshielded twisted pair. A cable medium with one or more pairs of twisted insulated copper conductors bound in a single sheath. Now the most common method of bringing telephone and data to the desktop.

UXGA. Computer screen resolution offering 1600 × 1200 pixels.

Variable bit rate. Operation where the bit rate varies with time during the decoding of a compressed bit stream.

VDA. See video distribution amplifier.

Vectorscope. An instrument similar to an oscilloscope that is used to check and/or align amplitude and phase of the three color signals (RGB).

Velocity of propagation. Speed of signal transmission. In free space, electromagnetic waves travel at the speed of light. In coaxial cables, this speed is reduced by the dielectric material. Commonly expressed as percentage of the speed in free space.

Vertical interval. The portion of the video signal that occurs between the end of one field and the beginning of the next. During this time, the electron beams in the monitors are turned off (invisible) so that they can return from the bottom of the screen to the top to begin another scan.

Vertical interval switcher. A sequential or matrix switcher that switches from one camera to another exactly in the vertical interval, thus producing roll-free switching. This is possible only if the various camera sources are synchronized.

Vertical resolution. Chrominance and luminance detail expressed vertically in the picture tube. Limited by the number of scan lines.

Vertical retrace. The return of the electron beam to the top of a television picture tube screen or a camera pickup device target at the completion of the field scan.

Vertical shift register. The mechanism in CCD technology whereby charge is read out from the photosensors of an interline transfer or frame interline transfer sensor.

Vertical sync pulse. A portion of the vertical blanking interval that is made up of blanking level. Synchronizes vertical scan of television receiver to composite video signal. Starts each frame at same vertical position.

Vestigial sideband transmission. A system of transmission wherein the sideband on one side of the carrier is transmitted only in part.

VGA. Video graphics array with resolution of 640 × 480 pixels.

Video bandwidth. The highest signal frequency that a specific video signal can reach. The higher the video bandwidth, the better the quality of the picture. A video recorder that can produce a very broad video bandwidth generates a very detailed, high-quality picture on the screen. Video bandwidths used in studio work vary between 3 and 12 MHz.

Video distribution amplifier (VDA). A special amplifier for strengthening the video signal so that it can be supplied to a number of video monitors at the same time.

Video equalization corrector (video equalizer). A device that corrects for unequal frequency losses and/or phase errors in the transmission of a video signal.

Video framestore. A device that enables digital storage of one or more images for steady display on a video monitor.

Video gain. The range of light-to-dark values of the image that are proportional to the voltage difference between the black and white voltage levels of the video signal. Expressed on the waveform monitor by the voltage level of the whitest whites in the active picture signal. Video gain is related to the contrast of the video image.

Video in-line amplifier. A device providing amplification of a video signal.

Video matrix switcher (VMS). A device for switching more than one camera, VCR, DVR, video printer, and similar to more than one monitor, VCR, DVR, video printer, and the like.

Video monitor. A device for converting a video signal into an image.

Video printer. A device for converting a video signal to a hard-copy printout. It could be a monochrome (B/W) or color. They come in different format sizes. Special paper is needed.

Video signal. An electrical signal containing all of the elements of the image produced by a camera or any other source of video information.

Video switcher. A device for switching more than one camera to one or more monitors manually, automatically or upon receipt of an alarm condition.

Video wall. A video wall is a large screen made up of several monitors placed close to one another, so when viewed from a distance, they form a large video screen or wall.

VITS. Video insertion test signals. Specially shaped electronic signals inserted in the invisible lines (in the case of PAL, lines 17, 18, 330, and 331) that determine the quality of reception.

VOD. Video on Demand. A service that allows users to view whatever program they want whenever they want it with VCR-like control capability such as pause, fast forward, and rewind.

VHF. Very high frequency. A signal encompassing frequencies between 30 and 300 MHz. In television, VHF band I uses frequencies between 45 MHz and 67 MHz, and between 180 MHz and 215 MHz for Band III. Band II is reserved for FM radio from 88 MHz to 108 MHz.

VHS. Video home system. As proposed by JVC, a video recording format used most often in homes but also in CCTV. Its limitations include the speed of recording, the magnetic tapes used and the color separation technique. Most of the CCTV equipment today supersedes VHS resolution.

VLF. Very low frequency. Refers to the frequencies in the band between 10 and 30 kHz.

VMD. Video motion detector. A detection device generating an alarm condition in response to a change in the video signal, usually motion, but it can also be a change in light. Very practical in CCTV as the VMD analyzes exactly what the camera sees (i.e., there are no blind spots).

VR. Virtual Reality. Computer-generated images and audio that are experienced through high-tech display and sensor systems and whose imagery is under the control of a viewer.

VS. Vertical sync.

WAN. Wide Area Network.

Waveform monitor. Oscilloscope used to display the video waveform.

Wavelet. A particular type of video compression that is especially suitable for CCTV. Offers higher compression ratio with equal or better quality to JPEG.

White balance. An electronic process used in video cameras to retain true colors. It is performed

electronically on the basis of a white object in the picture.

White level. This part of the video signal electronically represents the white part of an image. It resides at 0.7 V from the blanking level, whereas the black part is taken as 0 V.

Wow and flutter. Wow refers to low-frequency variations in pitch while flutter refers to high-frequency variations in pitch caused by variations in the tape-to-head speed of a tape machine.

WSGA. Computer screen format offering 1640 × 1024 pixels resolution.

WUXGA. Computer screen resolution offering 1920 × 1280 pixels. This covers the HDTV.

W-VHS. A new wide-VHS standard proposed by JVC, featuring a high-resolution format and an aspect ratio of 16:9.

XGA. Computer screen format offering 1024 × 768 pixels resolution.

Y/C. A video format found in Super-VHS video recorders. Luminance is marked with Y and is produced separate to the C, which stands for chrominance. Thus, an S-VHS output Y/C requires two coaxial cables for a perfect output.

Y, R-Y, B-Y. The general set of component video signals used in the PAL system as well as for some encoder and most decoder applications in NTSC systems; Y is the luminance signal, R-Y is the first color difference signal, and B-Y is the second color difference signal.

Y, U, V. Luminance and color difference components for PAL systems; Y, B-Y, R-Y with new names; the derivation from RGB is identical.

Z. In electronics and television this is usually a code for impedance.

Zoom lens. A camera lens that can vary the focal length while keeping the object in focus, giving an impression of coming closer to or going away from an object. It is usually controlled by a keyboard with buttons that are marked zoom-in and zoom-out.

Zoom ratio. A mathematical expression of the two extremes of focal length available on a particular zoom lens.

Appendix B

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Appendix C

All the CCTV links in the world

www.cctvlabs.com

On the following pages you will find a worldwide listing of all the known CCTV businesses until November 2004, courtesy of the CCTV Labs team.

It is available at the ***www.cctvlabs.com*** web site, under the ***CCTV Central***.

This information has been collected by the CCTV Labs team over the period of nearly 10 years.

The information is as accurate as submitted by the appropriate representatives. All submissions are always checked for their availability and content before it is listed on the CCTV Central web site.

I encourage your feedback with suggestions, corrections or new companies and their details.

Please e-mail such details to *cctvlabs@cctvlabs.com*.

Thank you for your understanding and I hope you do find this listing helpful.

The author

Sydney

November, 2004

0 ~ 9

00 Security Cameras (USA) http://www.00security-cameras.com/
1 Volt Associates Inc. (USA) http://www.1volt.com/
123 CCTV (USA) http://www.123cctv.com/
2020 DSS (Canada) http://www.2020dss.com/
2B Security Systems (Denmark) http://www.2bsecurity.com/
360 Vision Technology (UK) http://www.2bsecurity.com/
3rdEye Video (USA) http://www.3rdeyevideo.com/
3R Technologies (Korea) http://www.3r.co.kr/
3V (Poland) http://www.3v.pl/
4NSys (Korea) http://www.4nsys.com/eng/
8×8 (USA) http://www.security.8x8.com/

A

ABC CCTV (USA) http://www.abccctv.com/
Academy of Infrared Thermography (Canada) http://www.infraredtraining.net/
Accel Security (USA) http://www.accelsecurity.com/
ACC Vigilant (France) http://www.accvigilant.com/
AceHawk (Korea)
ACI International Inc. (USA) http://www.aciconnect.com/
AClass Enterprises (Australia) http://www.aclass.com.au/
ADACS Systems Pty.Ltd. (Australia) http://www.adacs.com.au/
Ademco (USA) http://www.ademco.com/
Adeva Technology Ltd. (UK) http://www.adeva.co.uk/
ADN Protective System (Pakistan) http://www.adnprotectivesystems.com/
ADPRO –Vision Systems (Australia) http://www.adpro.com.au/
Advanced Electronic Group (USA) http://www.aegi.com/
Advanced Security Systems (Australia) http://www.advanced.com.au/
Adyoron Intelligent Systems Ltd. (Israel) http://www.adyoron.com/
AGS Vision (Italy) http://www.agsvision.com/
AICSYS (Taiwan) http://www.aicsys.com/wmc-402m.php
Aitech Defense Systems Inc. (Canada/USA) http://www.rugged.com/video/
Allards CCTV (Australia) http://www.allardscctv.com/
Allguard (Australia) http://www.allguard.com.au/
allSpyCCTV (Portugal) http://www.allspycctv.com/
Allthings Sales & Service (Australia) http://www.allthings.com.au/
Alnet (Australia) http://www.alnetsystems.com.au/
Alpha I&C (Korea) http://cctv.tokebi.co.kr/
Alpha-Pribor (Russia) http://alpha.tula.net/
Alpha Systems (USA) http://www.aslrwp.com/
Altech Vision (Australia) http://www.altechvision.com.au/
Altronix (USA) http://altronix.com/
AltSys (USA) http://www.altsysonline.com/
AMG Systems (UK) http://www.amgsystems.co.uk/
AmebaCCTV (USA) http://www.amebacctv.com/

American Dynamics (Tyco) (USA) http://www.americandynamics.net/
American Fibertek (USA) http://americanfibertek.com/
AmperTech Inc. (USA) http://www.ampertech.com/
Analog Devices (USA) http://www.analog.com/video
AnexTek (Taiwan) http://www.anextek.com/
Anicom (USA) http://anicommm.com/
Applied Technologies Manufacturing Ltd. (UK) http://www.atmltd.co.uk/
Appro (Taiwan) http://www.approtech.com/
ARMT (Israel) http://www.armt.co.il/
Artnix (Korea) http://www.artnix.co.kr/
ASAP Technology (USA) http://www.asapcctv.com/
ASIAL (Australia) http://www.asial.com.au/
Asian World CCTV (Hong Kong) http://www.awcctv.com/
Asia Vision Technologies-VECON (Hong Kong) http://www.asiavision.com.hk/
A&S International (Taiwan) http://www.asmag.com/
Asian Sources Security Products http://www.asiansources.com/
ASMOT (Taiwan) http://www.asmot.com/
ASP CCTV (UK) http://www.asp-digital.co.uk/
Aspro Inc. (Canada) http://www.aspro.com/
AstraGuard (UK) http://www.astraguard.com/
"A" Tech Video Solutions (Canada) http://www.video-surveillance.com/
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AVS CCTV (USA) http://www.avscctv.com/
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B

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C

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CyberVision (Taiwan) http://www.cybervision.com.tw/
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Stanley Laboratories Ltd. (UK) http://www.stanlab.co.uk/
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ST Microelectronics (UK) http://www.vvl.co.uk/
Sunell (China) http://www.sunellsecurity.com/
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Sveistrup Elektronik A/S (Denmark) http://www.sveistrup.dk/
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TRC (Taiwan) http://www.trcctv.com/
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Verdant Technologies (UK) http://www.verdant-tech.co.uk/
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Zamir Recognition Systems (Israel) http://www.zamir.com/
Zone Digital Video Systems (Australia) http://www.zonecctv.com/
Zone Products (USA) http://www.zoneproducts.com/
Zoran (USA) http://www.zoran.com/
Zorba Security (India) http://members.rediff.com/zorbasecurity/
ZPSys (Korea) http://www.zpsys.com/
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Appendix D

Book co-sponsors

This book has been made possible not only by the publisher Elsevier (Butterworth-Heinemann), but also by the CCTV manufacturers who have believed in me and co-sponsored this edition.

The following pages are dedicated to their high-quality CCTV products, and they are listed in alphabetical order.


Protect your
current investment and
get all the benefits
of IP-Surveillance


PELCO
ANALOG
DIGITAL

About the author...



I was born in Macedonia in 1956. I graduated with a degree in electronics and telecommunications from the University Sv.Kiril and Metodij in Skopje (Macedonia), and my thesis, completed in 1982, was on CCD cameras.

After my graduation, I started working as a CCTV design engineer in a company called Video Engineering in Ohrid (Macedonia), where I started putting together my theory of television and its challenging practice. I was involved in the design and manufacture of cameras, monitors, amplifiers, power supplies, and other CCTV equipment. After a couple of years of working there, I joined the Republic's Radio and Television Company as the chief engineer on a local TV/FM station. I had a joyful two years of broadcasting television experience, and I participated in the first satellite TV reception experiment in Macedonia with experts from the European Broadcast Union (EBU) and engineers from Thomson LGT, in 1985. Later that year I was offered an R&D position in another electronics company in Ohrid where I designed a number of electronic products for commercial use. This job involved a complete design cycle, including prototyping, mechanical assembly design, testing, and defining production details.

In 1987, I moved with my family to Australia where my career started in TCN Channel 9 in Sydney as a maintenance engineer. I had a great time at Channel 9, especially with my involvement in the biggest television broadcasting event in Australia – the bicentennial global broadcast, in January 1988.

In the next few years I worked in a few CCTV companies in the capacity of CCTV project engineer, product manager, and trainer. In 1990 I started my own consulting company, CCTV Labs, offering a variety of services such as CCTV system design, consultancy, training, and publishing. In the years after 1990 I have conducted a lot of seminars all over Australia and overseas. This ultimately led to the idea of putting all my knowledge and experience in written form so it can be used by others, without their needing to go through all the odysseys I had to. This is how the original first edition of this book was created, after which I started publishing the ***CCTV focus*** magazine – a truly international bi-monthly magazine dedicated to the CCTV technology. This was basically an extension of the book, and it is now in its fifth year of publication, always keeping up to date with the latest products and technologies in CCTV. The ***CCTV focus*** magazine is basically a bridge between the books and the current CCTV developments, keeping the readers in sync with the latest technology.

CCTV is a rapidly growing and changing area and proves right the saying, "the more you know, the more you realize how little you know." That's one of the reasons I have put so much effort into preparing this book and the web pages on the Internet (***www.cctvlabs.com*** and ***www.cctv-focus.com***), hoping it will provide at least some answers for knowledge-thirsty people.

One thing that distinguishes humans from animals is that human offspring do not have to learn life from scratch, but rather they can build on the accumulated knowledge of their parents and grandparents.

I wish to think that I am one of those parents.

You can always contact me at vlado@cctvlabs.com.

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